THESIS

WATER QUALITY HYDROLOGY ON SURFACE MINED WATERSHEDS

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR

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Abstract of Thesis

WATER QUALITY HYDROLOGY ON SURFACE MINED WATERSHEDS

Water quality and discharge on four watersheds disturbed by surface coal mining at the Edna Mine in northwestern Colorado have been monitored for about three years. Water quality and discharge have also been monitored in an adjacent stream at points above and below the entrance of mine drainage into the stream. Dissolved solids inflow to the stream between these two points equaled 6.1×10^6 kg in 1974 and 5.3×10^6 kg in 1975 for an increase in dissolved solids load of two to three times along the reach of the stream adjacent to the mine. About 70 to 80 percent of the dissolved solids inflow occurs in April, May, and June. During spring runoff dissolved solids reach concentrations exceeding 700 mg/ℓ at the downstream monitoring site with corresponding concentrations of less than 150 mg/ℓ at the upstream site. Dissolved solids concentrations in combined runoff on the four mine watersheds ranged from annual averages of 1200 mg/ℓ to 3000 mg/ℓ . The pre-mining concentration of dissolved solids in combined runoff is estimated at 460 mg/ℓ with the higher concentrations on the mine watersheds attributable to the disturbance caused by mining. Mining increases the depth of water percolation from several meters or less on undisturbed land to about 20 meters on mined land. Data show that the disturbed geologic material in the spoils contains large quantities of soluble salts.

A single-equation model based upon water and mass balances has been developed which can predict the average annual TDS concentration of combined surface and subsurface runoff from a mined watershed. The model incorporates three hydrologic parameters, three chemical parameters, and the fraction of land disturbed by mining. Concentrations predicted using

the model on the Edna Mine watersheds had an average error of about 9 percent from the measured concentrations. Parameters in the model can be adjusted to simulate the effects of varied climatic and hydrologic conditions that may result from reclamation efforts. The model may prove to be a useful tool for the planning and management of water resources on surface mine lands.

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LIST OF SYMBOLS

Symbol	Description	Unit
A_m	Area of watershed disturbed by mining	L^2
A_n	Area of watershed undisturbed by mining	L^2
A_t	Total area of watershed	L^2
EC	Electrical conductivity	μmohs/cm
ET	Evapotranspiration	L^3/L^2
f_{dm}	Fraction of precipitation lost through deep percolation on mined land	
f_{dn}	Fraction of precipitation lost through deep percolation on natural land	
f_{em}	Fraction of precipitation lost through evapotranspiration on mined land	
f_{en}	Fraction of precipitation lost through evapotranspiration on natural land	
F_m	Fraction of watershed mined	
f_s	Fraction of combined runoff from entire watershed occurring as overland flow	
f_{sm}	Fraction of combined runoff from mined portion of watershed occurring as overland flow	
f_{sn}	Fraction of combined runoff from natural portion of watershed occurring as overland flow	
I	Inflow between Stations C2 and C6	L^3/T
K	Model parameter	
K'	Model parameter including deep percolation	
M	Subscript indicating mean value	
P	TDS concentration	mg/ℓ

LIST OF SYMBOLS (Cont'd)

Symbol	Description	Unit
P_{gm}	Average TDS concentration of subsurface water on mined land	mg/ℓ
P_{gn}	Average TDS concentration of subsurface water on natural land	mg/ℓ
P_m	Average TDS concentration of waters on mined land	mg/ℓ
P_n	Average TDS concentration of waters on natural land	mg/ℓ
P_s	Average TDS concentration of surface waters	mg/ℓ
P_{sm}	Average TDS concentration of surface water on mined land	mg/ℓ
P_{sn}	Average TDS concentration of surface water on natural land	mg/ℓ
P_t	Average TDS concentration of combined runoff from the total watershed	mg/ℓ
q	Volume of water per unit surface area	L^3/L^2
Q_2	Discharge at Station C2	L^3/T
Q_3	Discharge at Station C3	L^3/T
Q_6	Discharge at Station C6	L^3/T
Q_9	Discharge at Station C9	L^3/T
Q_{10}	Discharge at Station C10	L^3/T
q_{em}	Volume of evapotranspiration on mined land per unit surface area	L^3/L^2
q_{en}	Volume of evapotranspiration on natural land per unit surface area	L^3/L^2
q_{gm}	Volume of subsurface water on mined land per unit surface area	L^3/L^2

LIST OF SYMBOLS (Cont'd)

Symbol	Description	Unit
q_{gn}	Volume of subsurface water on natural land per unit surface area	L^3/L^2
q_m	Volume of water on mined land per unit surface area	L^3/L^2
q_n	Volume of water on natural land per unit surface area	L^3/L^2
q_p	Volume of precipitation on watershed per unit surface area	L^3/L^2
q_{pm}	Volume of precipitation on mined land per unit surface area	L^3/L^2
q_{pn}	Volume of precipitation on natural land per unit surface area	L^3/L^2
q_{sm}	Volume of overland flow on mined land per unit surface area	L^3/L^2
q_{sn}	Volume of overland flow on natural land per unit surface area	L^3/L^2
Q_t	Total discharge	L^3/T
q_t	Volume of water on total watershed per unit surface area	L^3/L^2
R	Model parameter, ratio of natural land to mined land	
r^2	Coefficient of determination	
S	Stage reading	L
ΔS	Change in storage volume within the watershed	L^3
t	Time	T
TDS	Total dissolved solids	mg/ℓ
V_d	Volume of deep percolation	L^3
V_e	Volume of evapotranspiration	L^3

LIST OF SYMBOLS (Cont'd)

Symbol	Description	Unit
V_g	Volume of shallow subsurface water	L^3
V_p	Volume of precipitation	L^3
V_s	Volume of overland flow	L^3
V_t	Volume of total runoff	L^3
σ	Standard deviation	

CHAPTER I

INTRODUCTION

Background

The United States and other industrialized nations are dependent upon fossil fuels to supply many of the raw materials needed to produce manufactured goods and generate much of the energy necessary to keep pace with rapidly growing demands. With petroleum exploration and production becoming increasingly difficult and prices inflated far above levels of just a few years ago coal is becoming an increasingly important alternative source of energy. Many coal-burning electrical generating plants are presently in operation and many more are planned for the near future but these facilities require enormous quantities of coal which must be mined by surface and underground methods. For example, Gordon (1973) reports that the six coal-fired plants planned or now operating in the Four Corners region of the southwestern United States will together consume an estimated 4.94×10^{10} kg of coal annually. Coal is also finding increased uses in chemical industries and may eventually prove to be an alternative to natural crude oil for the refining of gasoline and other fuels.

Fortunately, the United States contains sufficient coal reserves to meet future demands well into the twenty-first century. The production of this coal will result in the disturbance of large areas of land by surface mining. In 1973 the total surface-mined land in the United States exceeded 2,430,000 hectares and new land was being mined at the rate of 1880 hectares per week (Caudill, 1973). The vast coal deposits in such western states as Arizona, Montana, Wyoming, Utah, and Colorado will become a major source of coal for future energy needs in the west.

Colorado ranks seventh in the nation in recoverable reserves with 28% of the state underlain by bituminous and sub-bituminous coal-bearing strata (Landis, 1964).

Most mineral industries are of an extractive nature and, therefore, have the potential for adversely disturbing the environment. Surface coal mining results in the disturbance of large areas of land. The loss of aesthetic value is perhaps the most apparent affect of strip mining although not necessarily the most serious. Land use is affected by the removal of vegetation and top soil, unstable slopes can be created, and water quality can be degraded due to high sediment loads, the production of acid water, and high concentrations of dissolved solids in mine drainage. Both government and industry are concerned with the environmental implications of surface mining. In many states laws now require that mine spoils be graded, revegetated, or otherwise reclaimed. There is a growing awareness that a balance must be struck between environmental quality and the economic extraction of natural resources.

Many researchers have studied pollution problems associated with acid coal mine drainage in the eastern U. S.. These include studies by Collier et al. (1970), Emrich (1969), Federal Water Pollution Control Administration (1969), Ahmad (1973), and others. Acid mine water results from the sulfates of iron and aluminum in solution as a consequence of pyrite oxidation. Acid mine drainage is not common in Colorado and in most western coal fields because of lower sulfate content in western coal (Wentz, 1974). For example, Averitt (1969) found that 65% of the coal in the U. S. contains 1% or less total sulfur but that of coal found east of the Mississippi River, 43% contains 3% or more total sulfur. In Colorado 89.5% of the coal analyses listed by Walker and Hartner (1966)

contained 1% or less total sulfur and only 1.3% of the analyses contained 3% or more. Thus, much of the studies of eastern coal mine pollution associated with acid production is not applicable in western coal fields.

The major source of water quality degradation in western coal mines comes from high concentrations of dissolved solids in water flowing from mine spoils. Many of the coal bearing strata have a naturally high content of salts for potential solution by water. In areas disturbed by surface mining percolating water can more readily dissolve these salts from the freshly exposed rock in the spoil piles. The resulting increase in dissolved salts can have adverse affects on downstream water users.

The Colorado River which drains much of the area underlain by western coal deposits supplies water for parts of seven states and Mexico. A policy of non-degradation adopted by these states and the Environmental Protection Agency is designed to maintain salinity at or below present levels. To achieve this goal sources of high salinity must be recognized and dealt with. Present salinity levels are causing substantial economic losses to water uses and these losses will increase as salinity increases.

Investigators have attempted to attach monetary values to the degradation of water quality in the Colorado River. Estimates are made by assessing and projecting costs incurred by water users in the Lower Colorado River Basin. The present Bureau of Reclamation estimate (U. S. Department of Interior, 1974) shows a loss of 53 million dollars to water users in 1974 and this is expected to increase to 124 million dollars by the year 2000 if current trends continue. The proportion of salinity attributable to surface mining, although not known, is probably small at present but the effects of increased mining must be considered for future planning.

There are other potential problems which can result from surface mining. These include erosion of spoil banks, the release of undesirable amounts of heavy metals or other toxic materials into streams and ground water aquifers, adverse effects to stream biota, undesirable changes in the surface and subsurface hydrologic system, and loss of recreational, grazing, or agricultural land. Only recently has the reclamation of mine spoils in the arid and semi-arid west been undertaken seriously and much more study is needed before spoils can be routinely reclaimed.

The effects of surface mining and subsequent efforts to reclaim land must be assessed in terms of the climatic, hydrologic, and geologic conditions existing before, during, and after mining. It is by understanding the physical-chemical aspects of these factors and their relationship to potential pollution that useful conclusions and recommendations concerning surface coal mining can be made.

Purpose and Scope

The purpose of this study is to identify and define the degradation potential due to dissolved solids in surface and subsurface drainage from coal mine spoils and to develop a model which can predict what this potential will be under varying climatic, hydrologic, and geologic conditions. This study is one part of a broader study which includes aspects of sediment production from spoils and the development of a complex numerical computer model to explain the surface and subsurface water quality hydrology of mine spoils. The Edna Mine, located in northwestern Colorado, was selected as a study site. Data have been collected for approximately three years, allowing a detailed analysis of the water quality hydrology to be made. The water quality hydrology is examined using parameters relating to climate, hydrology, and geology.

The approach is to identify the extent of water pollution on the Edna Mine and then relate this to the availability of water and contaminants. Water quality monitoring stations were established at locations on the mined watersheds and water samples were analyzed for the type and amount of dissolved solids present. Data show that high concentrations of salts in subsurface water flowing from mine spoils is the most serious source of water quality degradation. Water quality samples were also collected at locations along a perennial stream into which mine water flows to determine the effect of mine drainage on the stream. Discharge measurements were made at various water quality stations in order to determine the quantity of water and dissolved salts flowing from the mine. In addition, soil and spoil samples were taken and subjected to saturated paste analysis to chemically characterize the contaminants available to water.

Throughout this study specific objectives have been followed in the collection and analysis of data. There are:

1. Measure the quantity and quality of surface and subsurface discharge from the mine.
2. Measure the influence of mine drainage on the water quality of an adjacent stream.
3. Determine by chemical analysis the potential contaminants present in the soil and spoils.
4. Relate the observed water quality characteristics to the potential contaminants available.
5. Develop a simple model to predict water quality degradation.
6. Test this model with data from the Edna Mine.
7. Demonstrate the usefulness of such a model.

Included as appendices of this report are data taken subsequent to June, 1974. Data taken prior to this time can be found in a report by McWhorter et al. (1975). Data from the prior report along with that presented in this report is analyzed to provide a detailed description of the water quality hydrology at the Edna Mine. In addition, a single-equation model is developed which relates the salt concentrations in mine drainage to certain aspects of climate, hydrology, and geology. If this model is proved valid with data from other areas disturbed by surface mining, then it can be useful to those in federal and state agencies and industry who must make decisions concerning reclamation, mining permits, and environmental impact with only limited data and expenditure.

CHAPTER II

PHYSICAL PROFILE

Physiography and Geology

The Edna Mine is located on the southeast edge of the Twentymile Park structural basin, about 24 kilometers southwest of Steamboat Springs, Colorado (Figure 2-1). The topography varies from gently dipping slopes on the eastern flanks of the numerous synclines in the area to steep slopes in the western flanks. The area is drained by tributaries of Trout Creek which in turn flows into the Yampa River near Milner, Colorado. Elevations above mean sea level on the Edna Mine range from 2134 m to 2530 m . The Little Trout Creek watershed, just south of the mine, reaches elevations up to 2775 m and the main Trout Creek watershed ranges from 1980 m to over 3350 m .

As described by Campbell (1923), Twentymile Park consists of a large structural basin surrounded by ridges of considerable height. The Edna Mine is located on the east limb of the Argo Syncline which forms a subordinate basin to Twentymile Park. The Argo Syncline is typical of other synclines in the area being asymmetric with dips on the west limb much steeper than those on the east limb. Most rock strata on the Edna Mine are dipping at about ten degrees to the west towards Trout Creek.

Figure 2-2 is a geologic map and Figure 2-3 (from Plate 18, USGS Bulletin 1027-D) is a general stratigraphic column of the Upper Cretaceous rocks in the region. The Mancos Shale is not exposed on the Edna Mine but conformibly underlies the younger Mesa Verde Group consisting of the Iles and Williams Fork formations. Present mining operations extract coal from the Wadge seam which is part of the Middle Coal group

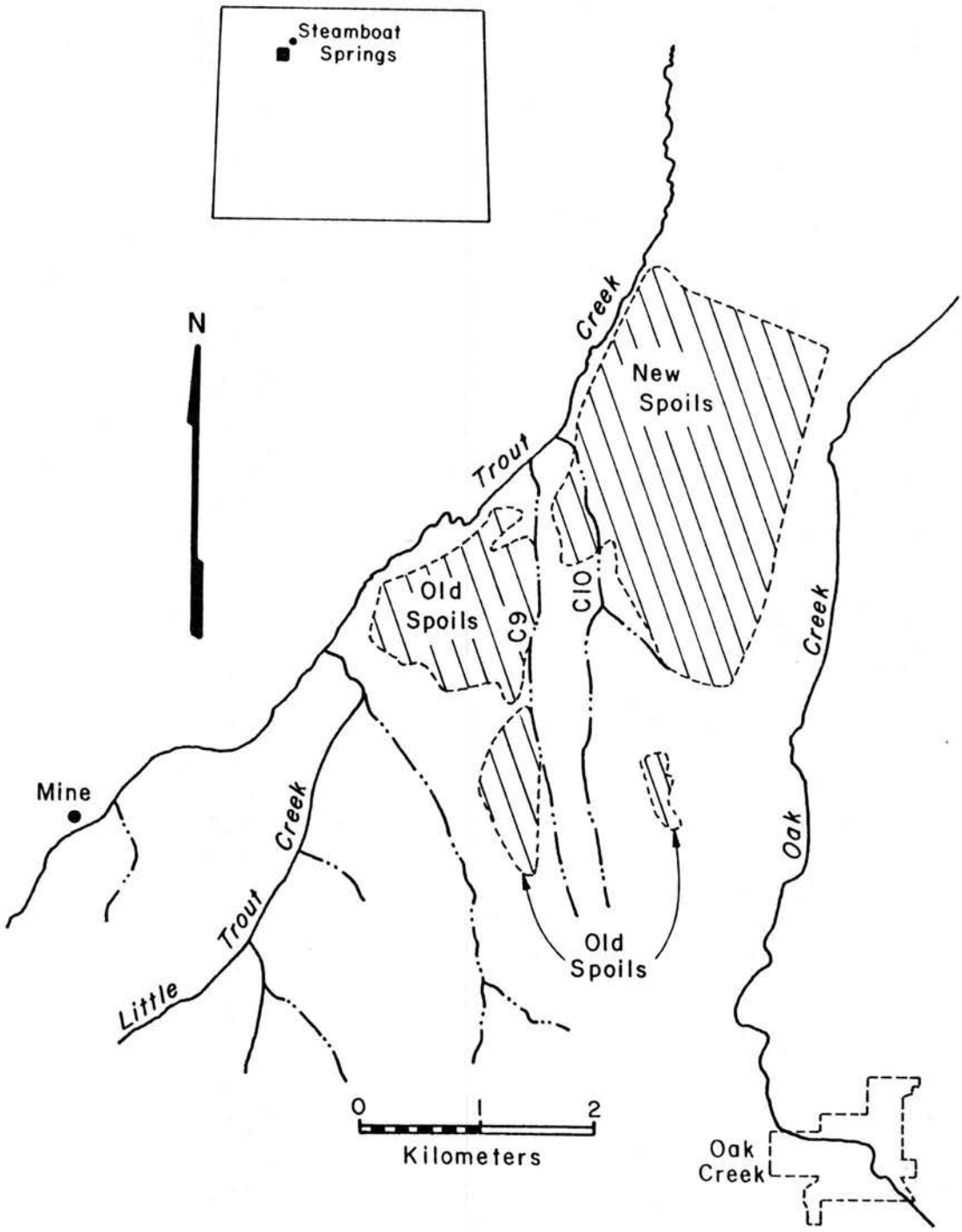

Figure 2-1. Location of the Edna Mine.

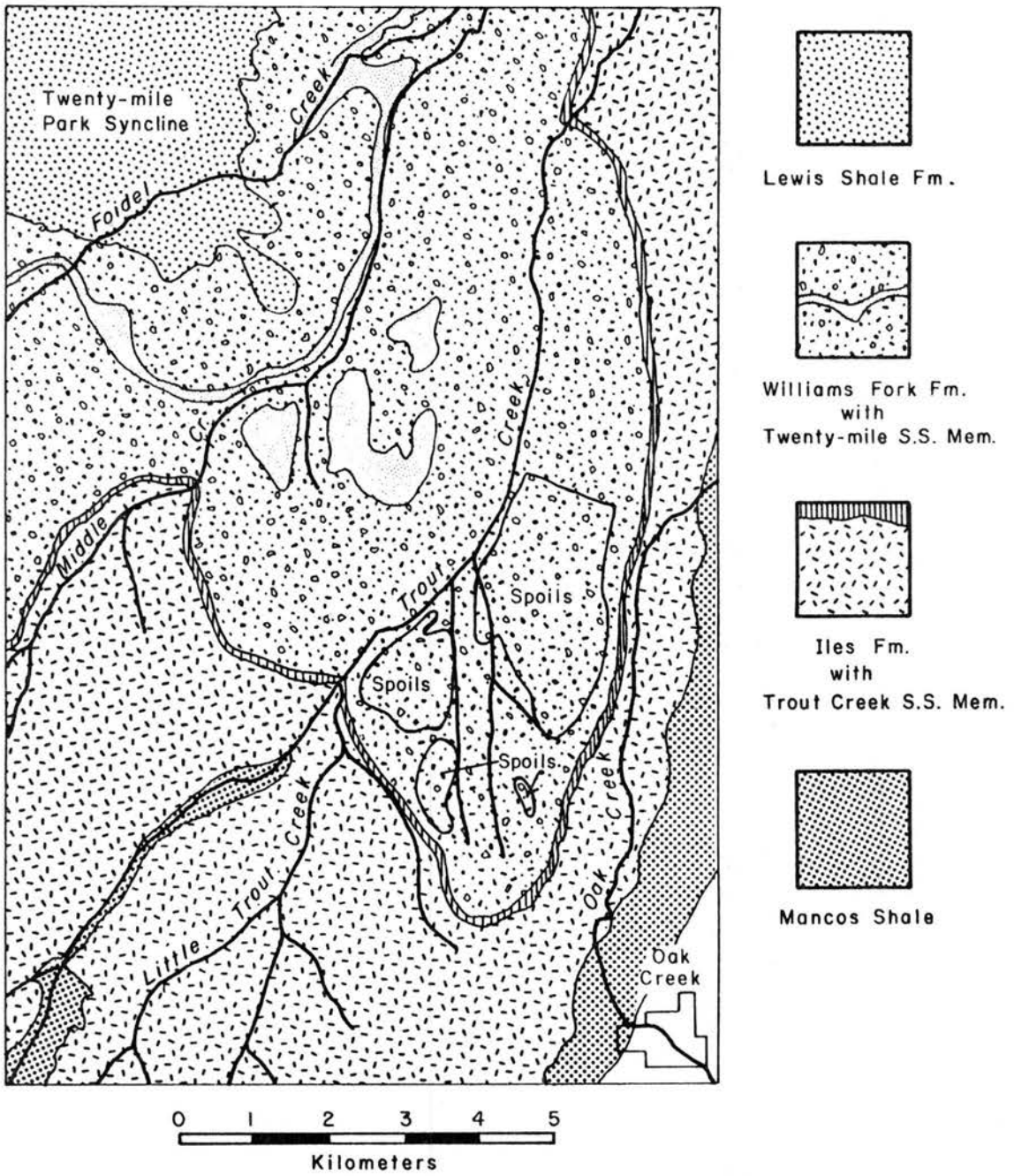

Figure 2-2. Geologic map of the Edna Mine and surrounding area.

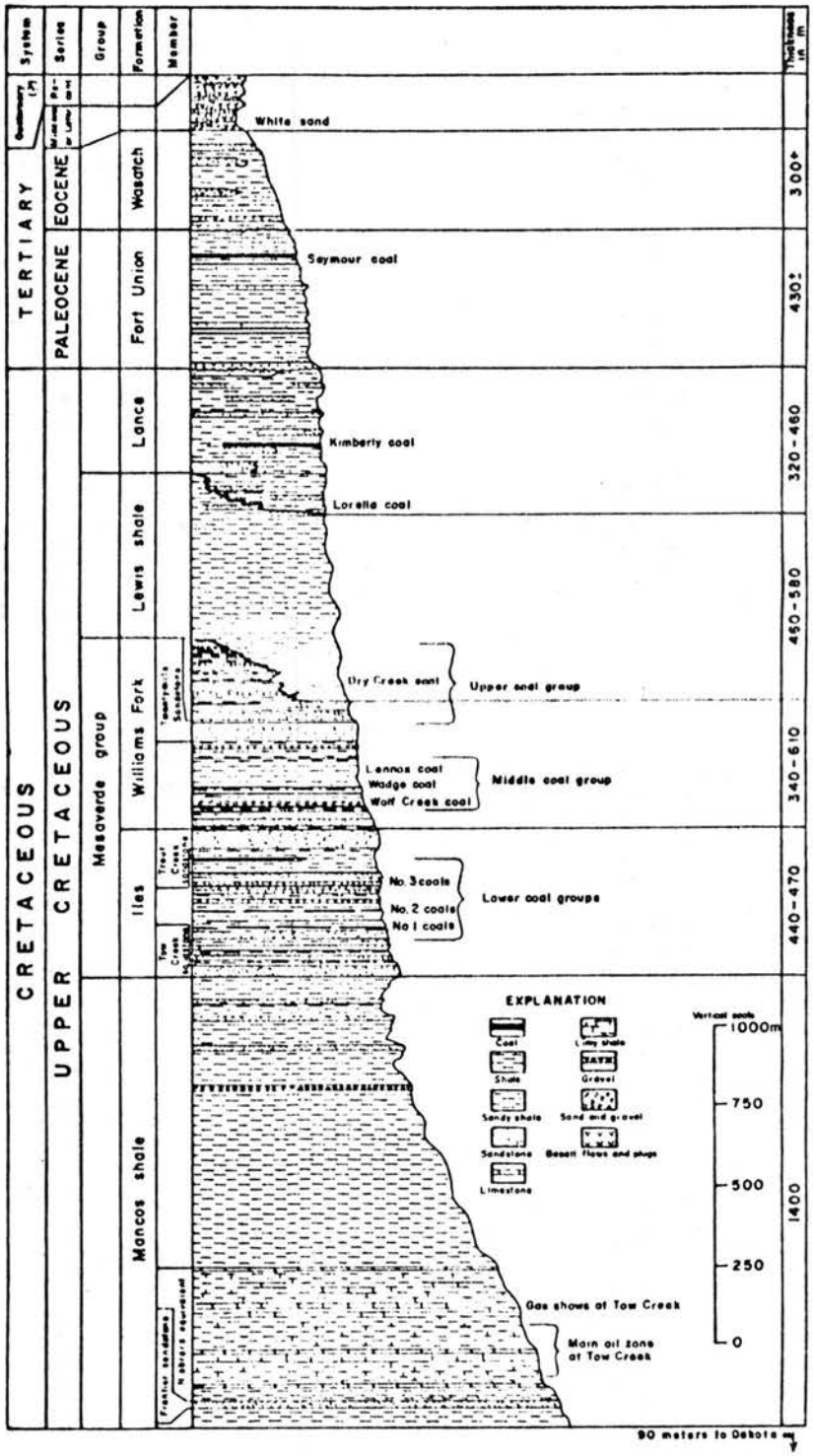

Figure 2-3. Stratigraphic column of exposed strata found in parts of northwestern Colorado.

of the Williams Fork formation. In some parts of northwestern Colorado, the Lewis shale conformibly overlies the Williams Fork formation. However, at the Edna Mine it has been eroded away along with the Twentymile sandstone member of the Williams Fork formation.

Bass et al. (1955) describe the Williams Fork formation as consisting of interbedded sandstone, sandy shale, and coal beds of marine brackish water and fresh water origin. Of the three bituminous coal beds in the Middle Coal group the Wadge is described as the most uniformly good in quality and workable thickness. Older surface mining operations during the 1940's extracted coal from the Lennox seam in the southern portion of the Edna Mine, but present operations are concentrated on the Wadge seam. The thickness of the Wadge ranges from about 1.5 m to 2.0 m over the mine. The Lennox seam is found 4.5 to 6.0 meters above the Wadge and ranges from 0.3 to 1.0 meter in thickness.

Mining Operations

Coal is extracted at the Edna Mine by a method of mining known as area or continuous surface mining. This method of mining is common in areas where the topography is fairly flat and the coal is found at relatively shallow depths. Area mining consists of digging a series of parallel cuts to expose and remove the coal. At the Edna Mine overburden is loosened with explosives and removed using a 26.8 cubic meter drag line. The exposed coal is then loaded in trucks and hauled out of the pit eventually to be transported by railroad. Cuts are made parallel to the strike of the slope and after one cut is completed the overburden removed in the next successive cut is deposited in the open tranch of the previous cut. The resulting parallel spoil ridges are then graded to conform with the original slope configuration, approximately.

Mining operations are currently located in the northern section of the mine near the top of the ridge between Oak Creek and Trout Creek. The Wadge seam is found at 15 to 22 meters below the ground surface in this area. The highwall and trench at the location of present operations are free from any water seepage indicating no water table existing at this depth and location.

Spoil piles in the older section of the mine south of current operations are not graded. Mining in this section was somewhat sporadic with pits opened and spoils piled to the sides. A map furnished by the Pittsburgh and Midway Company which currently operates the Edna Mine indicates that the Wadge was mined in only some areas with the Lennox seam most extensively mined.

Climate

No climatic record is available for the Edna Mine or the immediate vicinity so estimates of precipitation and potential evaporation are taken from U. S. Geological Survey maps (Irons et al., 1965). Mean annual precipitation is estimated to be 51 cm with about one-half of this amount occurring as snow. Potential evaporation is estimated to be about 81 cm annually. McWhorter et al. (1975) estimate the potential evapotranspiration of grasses on the mine to be 93 cm . Potential evapotranspiration thus exceeds precipitation by 30 or 40 cm on an annual basis. The temperature measured at Steamboat Springs (elev. 2063 m) located 24 km northeast of the Edna Mine ranges from an average -9°C in January to 17°C in July with the mean annual temperature equal to 4.1°C and 32 frost-free days. These temperatures are probably slightly lower than those at the Edna Mine due to Steamboat Springs closer proximity to

high mountains. Snowmelt on the mine occurs during April and May and in the upper reaches of Trout Creek during late May and June.

Vegetation and Soils

Natural vegetation on the Edna Mine consists of scrubbrush and grasses at the lower elevations with aspen groves at higher elevations. Older spoils in the southern area of the mine have been revegetated probably both naturally and by man and now support grasses and alfalfa. Portions of the newer spoils in the northern area of the mine have also been revegetated recently with grass and clover but vegetation is sparse and in some places almost nonexistant. The Little Trout Creek watershed is covered with coniferous and aspen forests over much of its area.

No detailed classification of soils was made, however, some soil samples were taken at various locations for chemical analysis. Soils on the mine with the exception of alluvial flood plain deposits along Trout Creek are residual being derived from the rocks of the Williams Fork formation. Soil over most of the natural land is thin and poorly developed with bedrock found in most places at depths of one meter or less. The soil is light brown to tan and contains a very clayey layer immediately above bedrock. Soil in areas with aspen groves is dark brown to black and may be up to five meters deep. The clay layer is again found near bedrock at locations sampled in the aspen groves.

The spoils have virtually no soil profile but instead are made up of weathered rock debris ranging from boulders several meters in diameter down to clay size particles. The spoil material exists down to the maximum depth of excavation where natural strata is found.

Hydrology

Trout Creek

Trout Creek, flowing northward along the base at the spoil piles, is the major surface drainage. The Trout Creek watershed above and including the Edna Mine is approximately 110 km^2 in area. The mean annual discharge of Trout Creek measured just downstream of the mine is estimated at 2.8×10^7 m^3/yr (McWhorter et al., 1975) or an equivalent of about 26 cm of water per year over the entire watershed.

Trout Creek has eroded a shallow canyon in parts of its reach along the west side of the mine as evidenced by vertical outcrops of Williams Fork rock. Within these confines Trout Creek meanders across an alluvial aquifer of unknown depth.

Edna Mine Watersheds

The Edna Mine is divided into individual watersheds which contribute to discharge monitoring stations C3, C5, C9, and C10 as shown in Figure 2-4. The watershed contributing to station C13 is also considered but is not shown in Figure 2-4. The watershed boundaries are chosen on the basis of surface water divides from topographic maps. These boundaries should also approximate the ground water divides on the Edna Mine. Table 2-1 indicates the mined and undisturbed land areas of each watershed. Inflow refers to the entire watershed area contributing water to Trout Creek between stations C2 and C6.

The surface water divides on undisturbed land are easily found by topographic highs between streams. However, on land disturbed by mining such divides are difficult to define and, in fact, may no longer exist. The spoil piles, both graded and ungraded, have very poor surface drainage patterns. This causes rainfall and snowmelt in some areas to pond

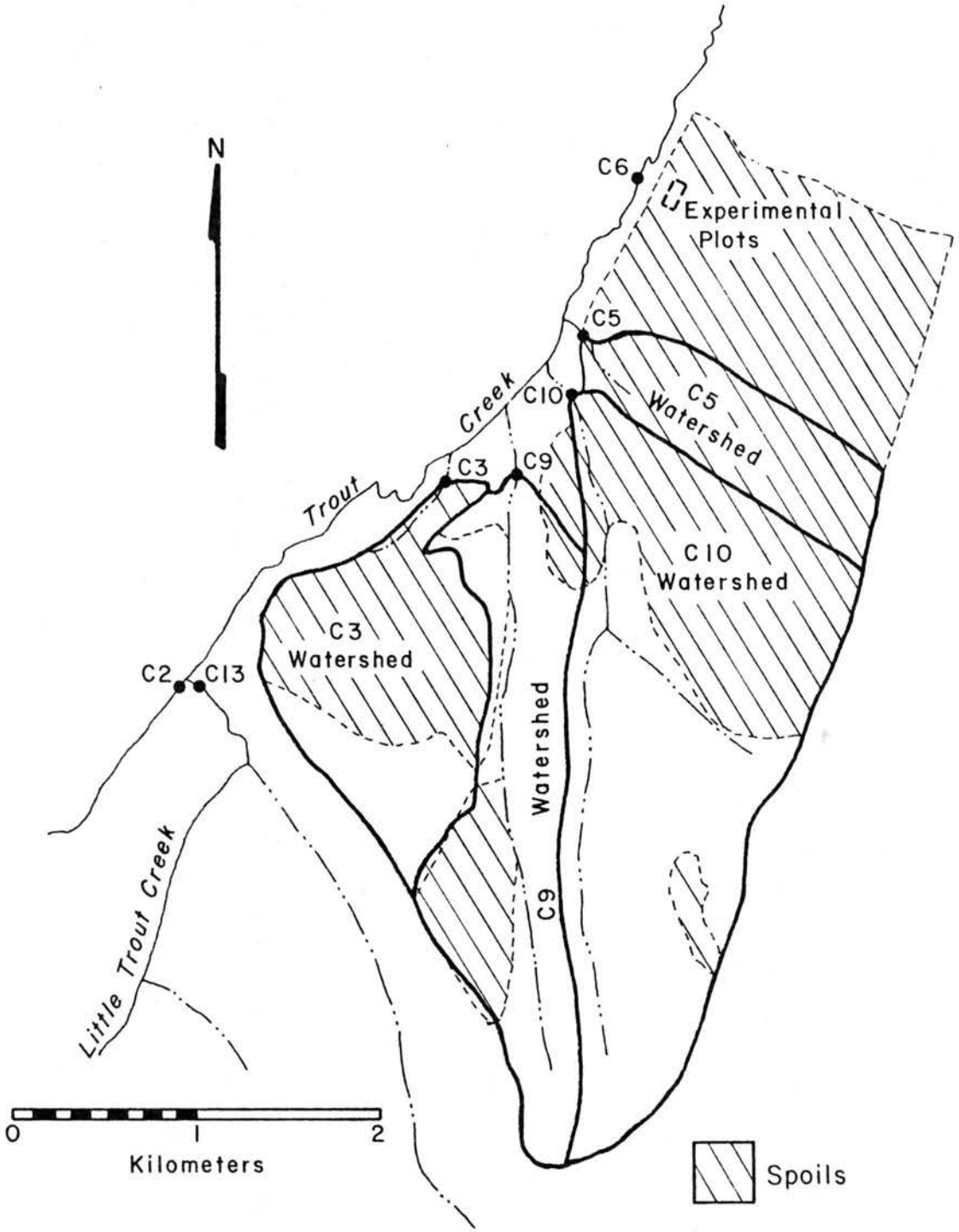

Figure 2-4. Individual watersheds on the Edna Mine and discharge monitoring stations.

Table 2-1

Watershed Areas

Watershed	Area mined (ha)	Area Unmined (ha)	Total (ha)	Fraction Mined
C3	116	55	171	0.68
C5	94	0	94	1.00
C9	72	132	204	0.35
C10	188	242	431	0.44
C13	0	2110	2110	0.00
Edna Mine*	689	503	1192	0.58
Inflow**	614	3042	3556	0.17

* Includes area north of Station C6.
** Includes total area between stations C2 and C6.

in depressions and infiltrate into the spoils with little or no overland flow. Northern portions of the mine probably had very little surface drainage even before mining. Present stream channels on the natural land north of the spoils carry water only during periods of very high runoff due to rain or snowmelt. Streams in the southern section of the mine exhibit better drainage patterns in their undisturbed reaches and flow for most of the year.

Because of low precipitation and poor surface drainage on the spoils much of the rainfall and snowmelt on the Edna Mine is lost by evapotranspiration or infiltrates into the ground. On natural land percolating water encounters relatively impermeable rock strata at shallow depths. The water then flows down dip to reappear in the stream channels on the mine site or to seep directly into Trout Creek.

Surface mining has significantly changed the natural surface and subsurface hydrologic conditions of the mined land. Figure 2-5 is a

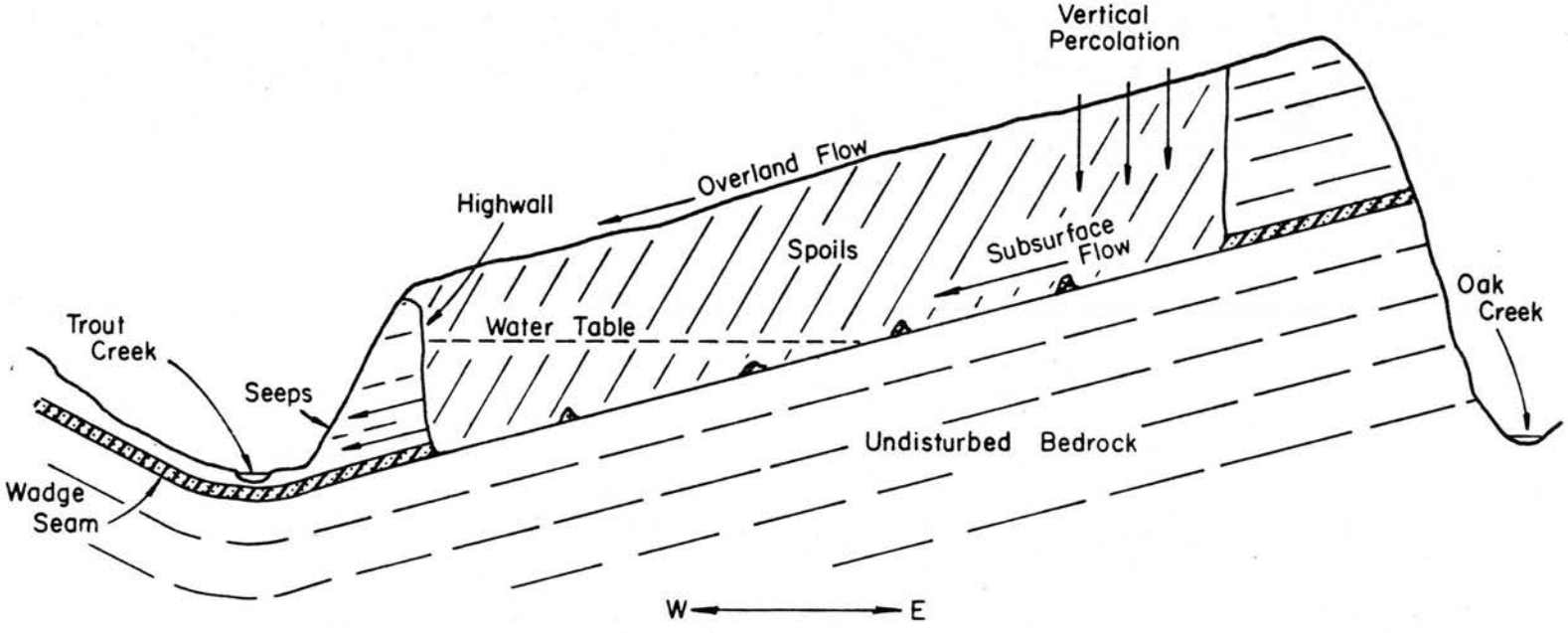

Figure 2-5. Schematic east-west cross-section near station C6.

schematic east-west cross-section through the northern region of the mine near station C6 showing conditions existing after mining. As water percolates into the spoils it encounters no rock strata at shallow depths but continues to flow vertically until reaching a water table or rock strata forming the lower boundary of the spoils. Thus the depth to which water percolates has been altered by mining from several meters or less to over fifteen meters. This significantly increases the potential for water to dissolve salts as it passes through the spoils.

As water flows down the dip of the rock strata beneath the spoils it encounters a highwall of undisturbed rock which parallels much of the east side of Trout Creek. This highwall is visible in the C3 watershed because a trench was left between it and the spoil piles. Water can be seen flowing from the base of the spoils and into this trench which forms a small pond behind station C3. It is assumed that most of the subsurface water from the C5, C9, and C10 watersheds reappears in the stream before flowing from the mine area. There is probably some subsurface water flowing out of these watersheds in the alluvial aquifers occurring below the stream channels. The volume of this underflow is probably small because of the shallow depth to bedrock and the narrow width of the stream valleys. The exact quantity of underflow is not known.

The spoil banks north of the C5 watershed apparently have no natural break in the highwall which is well hidden by the overlying spoils. Numerous subsurface seeps appear in the spring at the base of the spoils along Trout Creek. These may be the result of water flowing over the highwall or through it along fractures or permeable layers. It is possible that an aquifer forms behind the highwall which supplies water

to seeps until mid-summer. After this time there is no surface evidence of subsurface water from the spoils.

No data is available concerning deep ground water aquifers in the region. The rocks of the Williams Fork and Iles Formations seldom exhibit good aquifer characteristics. Ground water is most commonly associated with coal beds due to their highly fractured nature (Bureau of Land Management, 1975). For the purpose of this study the base of the spoils is assumed to be the maximum depth reached by percolating water.

Several small drainages enter Trout Creek from the west side between station C2 and station C6. However, their contribution to total inflow is probably small. Several irrigated fields located on the west side of Trout Creek adjacent to the mine probably contribute some return flow to Trout Creek. Thick vegetation along several exposed outcrops indicates some ground water seepage. The amount of water entering into Trout Creek from the west side was not monitored but, because of the small land area involved, its contribution to the inflow and salt load should also be small.

CHAPTER III

FIELD AND LABORATORY INVESTIGATIONS

Water quality and discharge were monitored and investigations were conducted both in the field and the laboratory in order to characterize the water quality hydrology at the Edna Mine. Saturated paste and leaching tests were also conducted to characterize the chemical properties of the soil and spoil material.

Field Studies

Water Quality Monitoring

Thirteen water quality monitoring stations were established on and near the Edna Mine with six stations located on Trout Creek, one on Little Trout Creek, five on the Edna Mine watersheds, and one on a natural watershed north of the mine. Figure 3-1 indicates the location and designation of these stations. Table 3-1 summarizes the location, installation date, and type of data obtained at each monitoring station.

Station C1 is located on Trout Creek upstream of all mining activity. Station C2 is about 2.5 kilometers downstream from Station C1 and is also downstream from one small underground coal mining operation. Other stations along Trout Creek include C4, C6, C8, and C11 with the first three located adjacent to the spoil piles and the latter located downstream from all mining activity. Little Trout Creek was sampled at Station C13 located near its confluence with Trout Creek.

Stations sampling water flowing from mine watersheds into Trout Creek include C3, C5, C7, C9, and C10. Station C3 sampled water flowing northward along the highwall trench in the older spoils where water can be seen seeping from the base of the spoil piles. Stations C9 and C10 are located on natural streams originating in the upper unmined portions

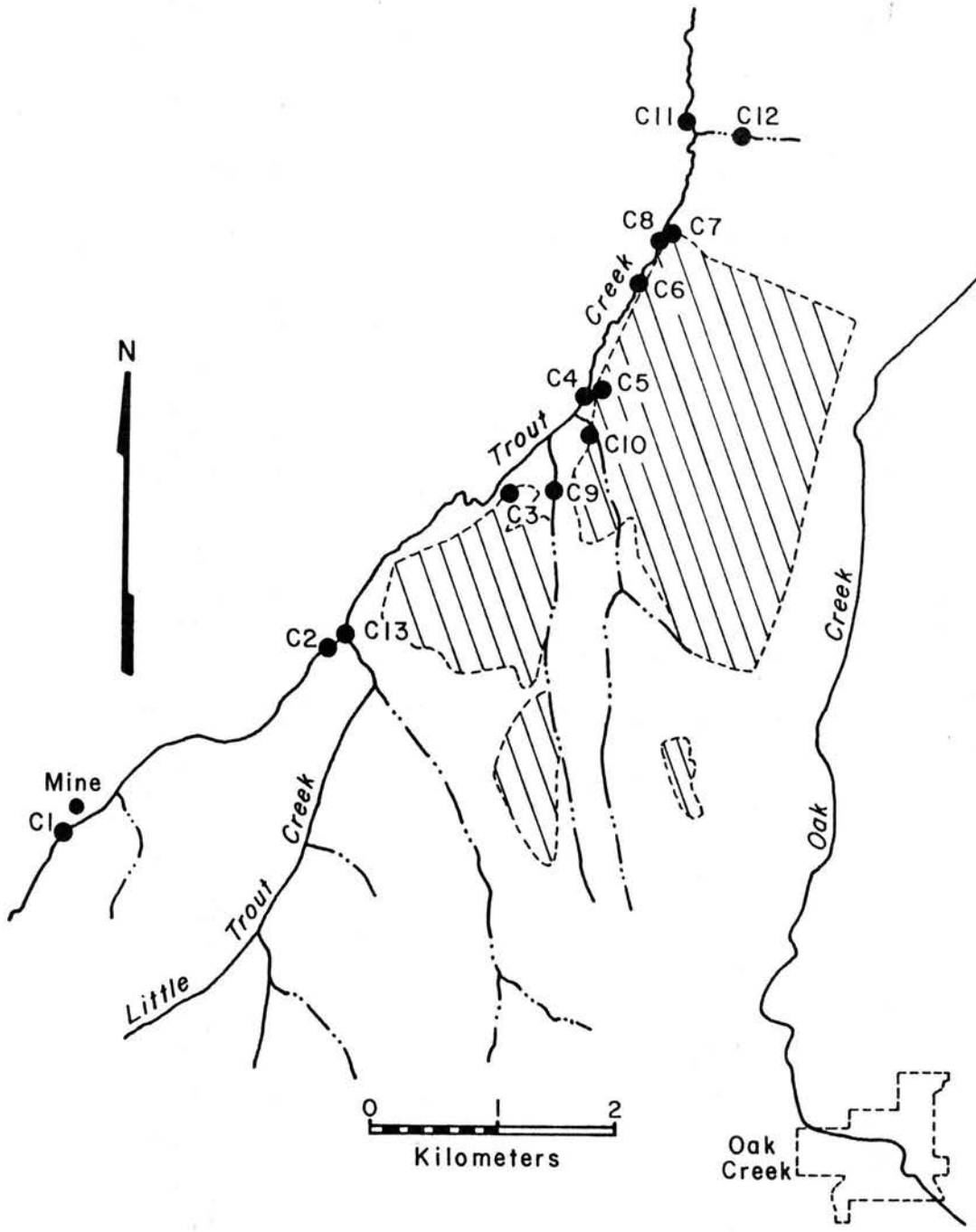

Figure 3-1. Location of water quality monitoring stations.

Table 3-1

Description of Water Quality and Discharge Monitoring Stations

Station Number	Type Quality	Type Discharge	Date Started	Description
C1	X		Oct, 1973	On Trout Creek above all mining activity
C2	X	X	Oct, 1973	On Trout Creek above Edna Mine
C3	X	X	Oct, 1973	On mine drainage in older spoils
C4	X		Oct, 1973	On Trout Creek adjacent to spoils
C5	X	X	Oct, 1973	On mine drainage in newer spoils
C6	X	X	Oct, 1973	On Trout Creek near northern limit of spoils
C7	X		Oct, 1973	On ground water seep from spoils
C8	X		Oct, 1973	On Trout Creek at northern limit of spoils
C9	X	X	Mar, 1975	On mine drainage in both newer and older spoils
C10	X	X	Mar, 1975	On mine drainage in newer spoils
C11	X		Mar, 1975	On Trout Creek approximately 0.8 km from northern extent of spoils
C12	X		Mar, 1975	On ephemeral stream north of Edna Mine
C13	X	X	Jul, 1975	On Little Trout Creek above Edna Mine

of watersheds which are disturbed by mining in their lower reaches. Water flowing from the base of the spoils in a deep unfilled cut was sampled at Station C5. Station C7 is located at a large subsurface water seep at the base of the spoil piles along Trout Creek. It has no associated surface drainage although there is some indication that a small natural drainage existed before mining. Station C12 is located on a small drainage on natural ground north of the spoils. It flows only during periods of very high runoff resulting in only a few water samples being collected.

Water samples were taken on a monthly basis at all stations with additional smaples taken every several days at stations C2, C3, C5, C6, C9, C10, and C13 from April through August of 1975 and April through May of 1976. A complete chemical analysis was performed on the monthly samples at most stations and all monthly samples were tested for pH, specific conductance, and total dissolved solids. The more frequent samples taken during the spring and summer were tested only for specific conductance.

During April and May of 1976 additional water quality samples were taken at the supplementary locations shown in Figure 3-2. These samples were tested for specific conductance and were not taken on a regular basis.

Discharge Monitoring

Discharge monitoring stations were established at several of the water quality stations to determine the total runoff and salt load of the surface drainage. Discharge was measured at stations C2 and C6 on Trout Creek by using a current meter to determine the velocity distribution in a stream cross-section. The corresponding water level was read from a staff gage installed near the measured cross-section. By taking

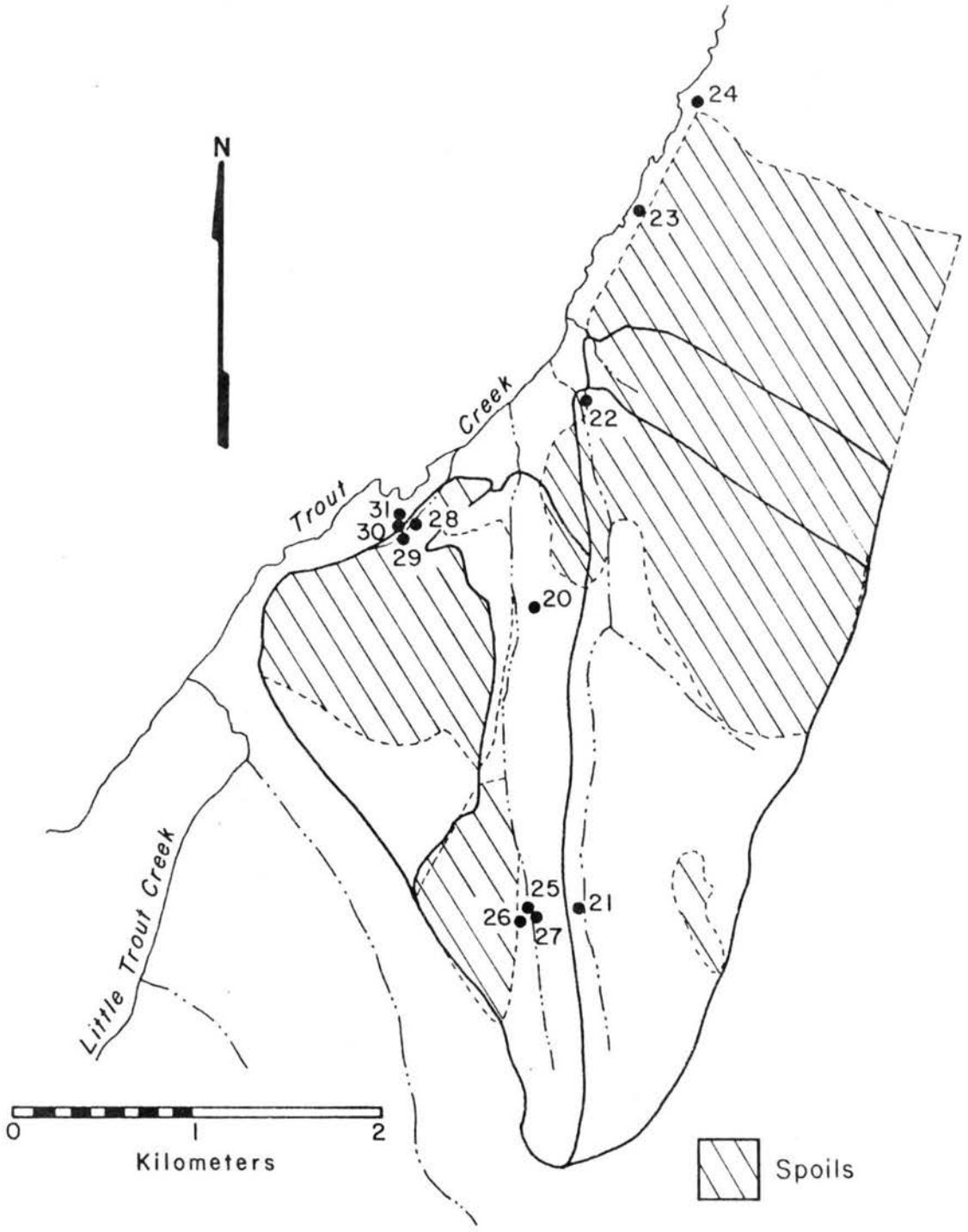

Figure 3-2. Supplementary water sample locations.

flow measurements of several different water levels, a stage-discharge relationship was found by fitting readings to an equation of the form

$$Q = aS^b$$

where Q is the discharge, S the staff gage reading, and a and b regression coefficients. It was found that significant erosion and deposition occurred in Trout Creek from one year to the next resulting in a change in the channel cross-section. The stage-discharge relationships were adjusted as new stream gaging data became available. Figures 3-3 and 3-4 are the rating curves for Stations C2 and C6, respectively. They demonstrate the variation in the stage-discharge relationship over a period of three years. In addition to a staff gage, Station C2 was equipped with a continuous water level recorder on April 21, 1975.

Stations C3, C9, and C10 were equipped with 20.3 cm by 91.4 cm cutthroat flumes and staff gages. Stevens Recorders were also installed on the flumes at these locations for continuous discharge monitoring. Ice in the stilling wells during the early spring prevented reliable records until temperatures warmed up in early April. Recorder charts were changed weekly and were constantly checked for accuracy with staff gage readings.

Stations C5 and C13 were equipped with flumes but not recorders. A 7.6 cm by 91.4 cm cutthroat flume and staff gage was installed at Station C5. However, the capacity of the flume was exceeded in April of 1975 so a larger 30.5 cm by 91.4 cm cutthroat flume was installed before the spring of 1976. A 0.46 cm by 2.74 cm Parshall flume and staff gage was installed during July 1975 at Station C13. Flow in Little Trout Creek exceeded the capacity of the flume for about a week during late May 1976.

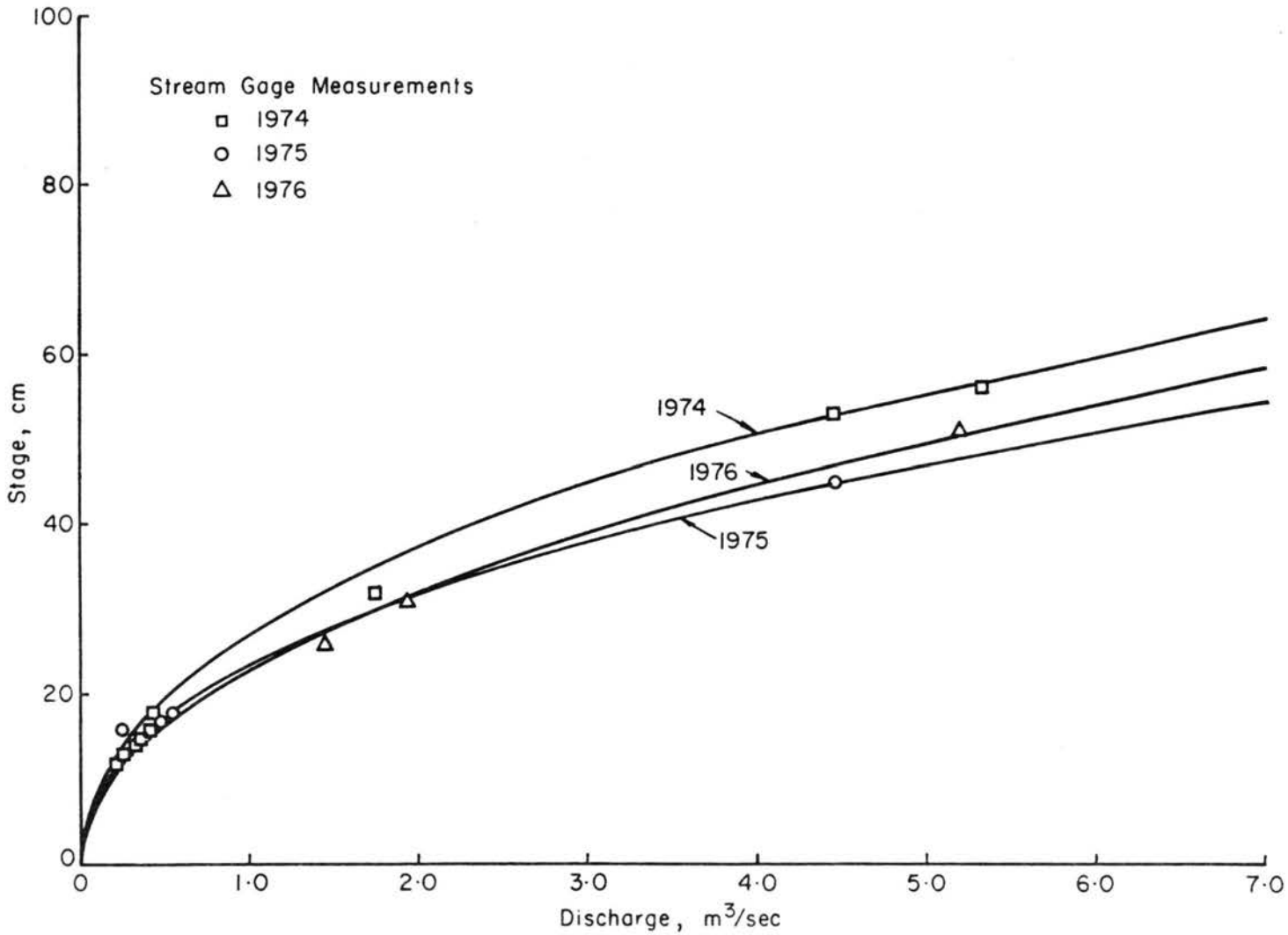

Figure 3-3. Stage-discharge rating curves for Trout Creek at Station C2.

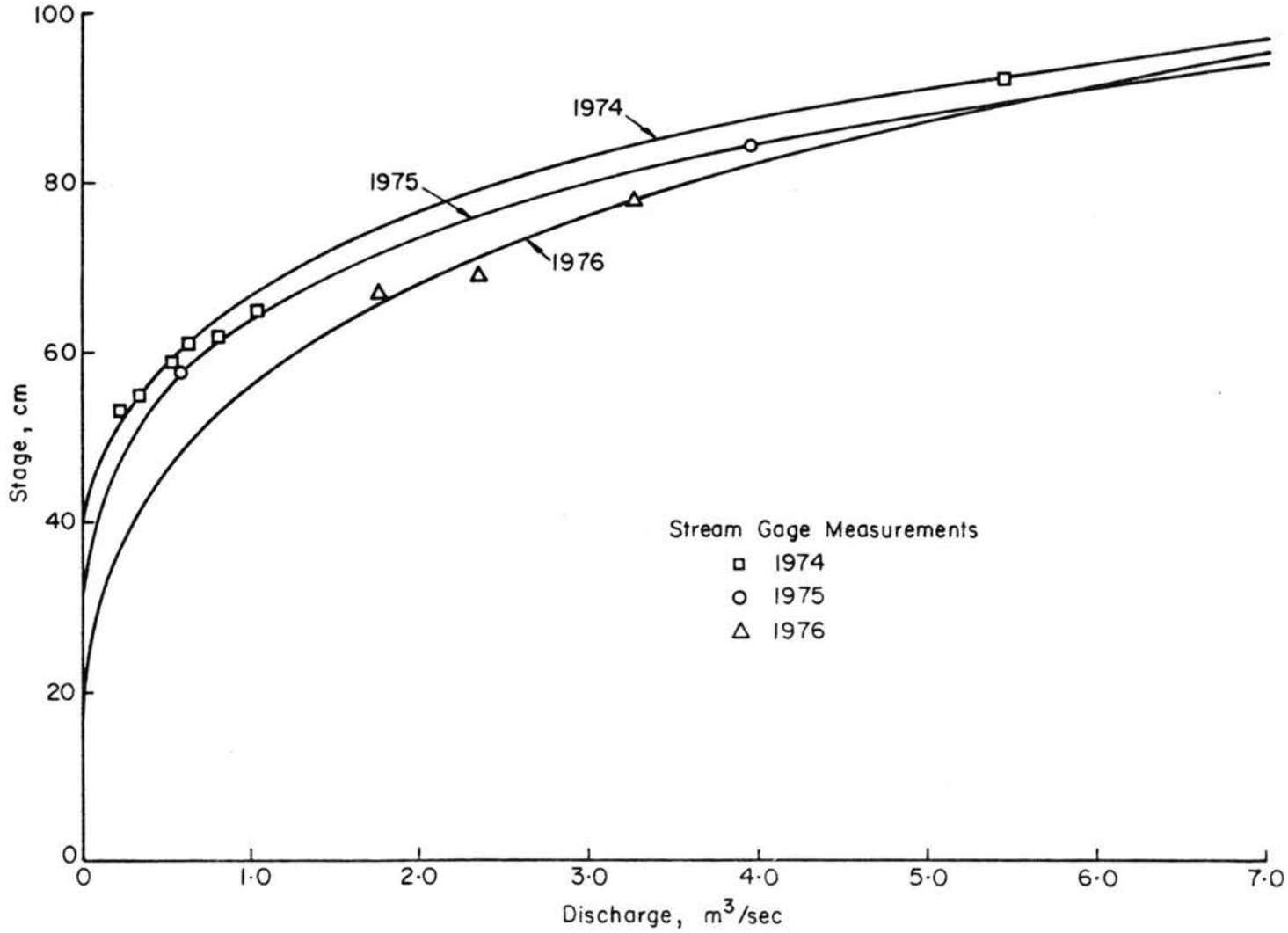

Figure 3-4. Stage-discharge rating curves for Trout Creek at Station C6.

Soil and Spoil Sampling

Samples of native soil and spoils taken at the Edna Mine are used to chemically characterize the surface and subsurface geologic material. In 1973 spoil samples were taken at eight locations on the mine (McWhorter et al., 1975). Three locations at the extreme north end of the spoils, three locations east of Station C4, and two locations south of Station C3 were sampled every 15 cm to a depth of 120 cm . A number of samples were taken at four locations along the active highwall by collecting drill cuttings at three meter intervals from ground surface to the coal seam. These samples were later composited. Native soil was sampled to a depth of one meter at one location during the same year.

In May 1976 samples were collected with a hand auger at locations shown in Figure 3-5. These locations include ones in the old spoils, the new spoils, and natural ground. They are coded as SS100 to SS109 with the depth of the sample also indicated. One sample was taken at the surface at all locations. However, in some cases it was impossible to take deep samples because rock was encountered.

Experimental Plots

Four experimental plots consisting of volumetric lysimeters with a water application system were constructed as part of a broader study (not included in this report) primarily for calibrating a numerical computer model of the spoil chemistry and hydrology and secondarily for sediment production studies. Water samples from the plots are referred to in this report, however, so a brief description of the plots is given.

The plots were constructed on the northern spoil piles in two natural depressions which were shaped and filled by bulldozers to fit the plot dimensions. The plots are rectangular in shape measuring about

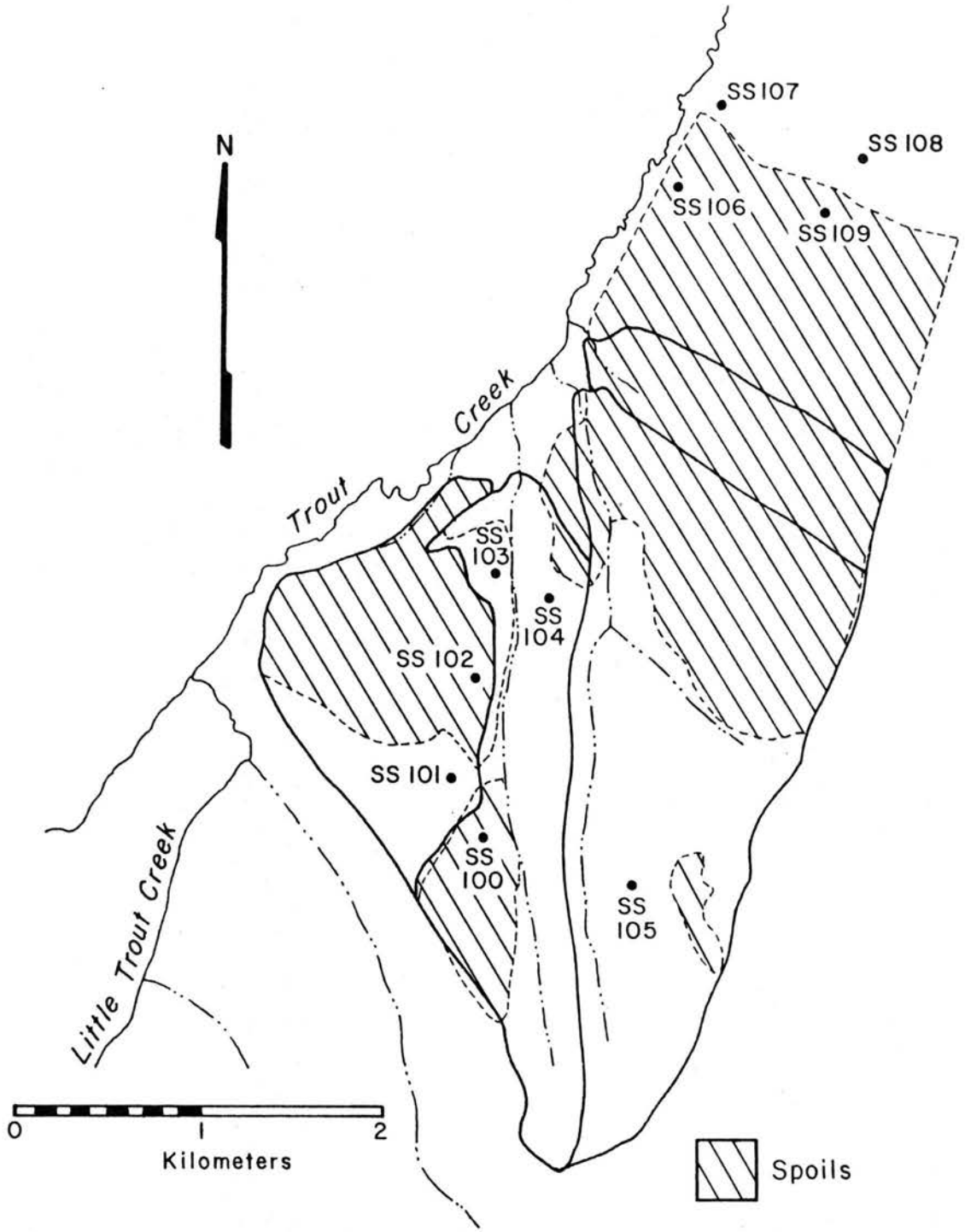

Figure 3-5. Location of soil and spoil samples taken in May, 1976.

9.1 m long, 3.7 m wide, and 3.5 m deep . They consist of spoil material surrounded by a plastic membrane with a gravel layer and a drain at the bottom. The surfaces of the plots were graded to slopes of 1, 3, 5, and 7 percent and a galvanized steel collection trough was installed at the lower end of each plot. Neutron probe access tubes and tensiometers were installed to measure the soil moisture profile within the plot. Water was applied to the surface and, during and after application, samples were obtained from the surface and subsurface drains.

Laboratory Studies

Water Analysis

Monthly water samples taken from October 1973 to May 1976 were analyzed for acidity, alkalinity, total hardness, pH, specific conductance, suspended solids, total dissolved solids, and total solids along with concentrations of aluminum, calcium, chloride, copper, dissolved iron, undissolved iron, total iron, potassium, magnesium, manganese, sodium, lead, sulfate, and zine. The monthly samples were collected and analyzed in accordance with the standard Environmental Protection Agency "Methods for Chemical Analysis of Water and Wastes" (U. S. Department of the Interior, 1970).

Water samples not subjected to chemical analysis were tested for electrical conductivity using a portable soil moisture bridge apparatus. Electrical conductance or specific conductivity is a measure of the ability of a substance to conduct electric current which in turn can be related to the concentration of total dissolved solids. The American Society for Testing and Materials (1966) has defined electrical conductivity as "the reciprocal of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specific

temperature." The units shall be "micromhos per centimeter at t°C" where temperature is usually reported at 25°C. Pure liquid water has a very low conductance, only a few hundredths of a micromho per centimeter at 25°C.

Since electrical conductance varies with temperature, it is important to measure the temperature along with the resistance. In dilute solutions for most ions an increase of 1°C increases the electrical conductance by about 2 percent (Hem 1970). Factors used to adjust electrical conductivity were obtained from Figure 3-6 which is based on a 0.01 molar potassium chloride solution (American Public Health Association et al., 1971). After electrical conductivity is adjusted to 25°C, it can be converted to the concentration of total dissolved solids by using a relationship developed in Chapter IV.

Soil and Spoil Analysis

The most important factor determining the composition of water is the concentration and type of solutes available in the soil and rock strata. As water precolates into the ground, several processes can change the type and amount of dissolved solids.

Ion exchange is a reversible process by which cations and anions are exchanged between solid and liquid phases and between solid phases if in close enough contact. This process does not change the total concentration in milliequivalents per liter of the solution but it does change the ionic composition. Solid components in the soil or spoils are also capable of adsorbing or releasing (desorption) solutes from or to the solution. This process can increase or decrease the total concentration of solutes in percolating water and is probably the major

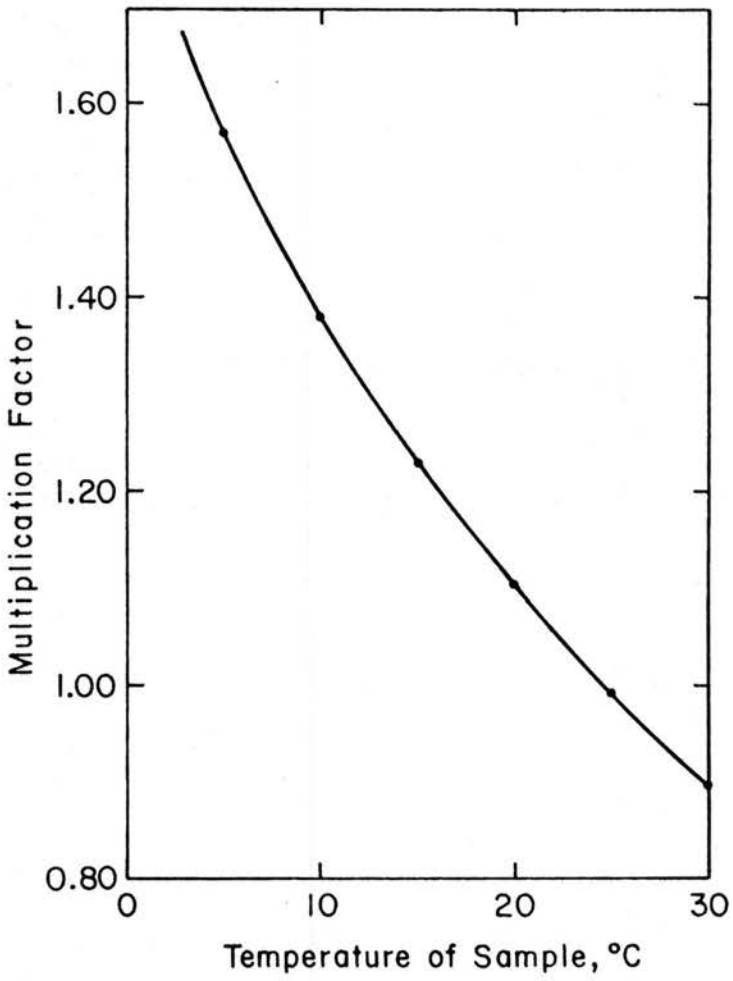

Figure 3-6. Factors for adjusting specific conductance of water to equivalent values at 25°C (based on a 0.01 M KCl solution).

process causing water in the Edna Mine spoils to increase in total dissolved solids concentration.

Salts found in the soil or the spoils may be readily soluble in water and thus quickly leached or only sparingly soluble and thus only slowly leached by water. Studies indicate that shale in western Colorado will contain $CaSO_4$ as a slightly soluble salt and $MgSO_4$ and $NaSO_4$ as soluble salts (Schmehl and McCaslin, 1969).

The saturated paste method was used to analyze the chemical constituents of the soil and spoil samples from the Edna Mine. It is assumed that this method would best indicate the potential amounts of soluble ions available to percolating water. Other factors which have an influence on the pollution potential of spoils such as weathering, microbial activity, acid formation, evapotranspiration, and non-equilibrium reactions are not characterized by saturated paste analysis.

Saturated paste tests were conducted by procedures described by Hergert (1971). The sample is dried and crushed until it will pass through a 2 mm screen. It is then saturated with distilled water, thoroughly mixed and left to stand for 16 hours. The resulting water extract is analyzed for the various chemical constituents desired. For the spoil samples taken in 1973, determinations were made for pH, specific conductance, calcium, magnesium, sodium, carbonate, bicarbonate, chloride, sulfate, and nitrate. The samples taken in May 1976 were tested only for specific conductivity.

Leaching Analysis

Two soil samples from depths of 70 cm and 100 cm were taken at the experimental plots and combined to yield a 558.8 g sample used for leaching tests. The sample was placed in a column 6.85 cm in diameter

containing glass beads at the bottom to retain the sample. The purpose of the test was to determine leaching and weathering characteristics of the spoils.

The spoil sample was initially sifted into the column to provide an even distribution. De-ionized water was added to the sample and maintained at a height of about 5 cm above the top of the sample. Water samples were taken for every 100 ml increment of leaching volume and tested for pH and specific conductivity. These water samples were then combined at 500 ml increments for further chemical analysis.

The test was conducted such that after an initial leaching volume was added, the sample was drained and air pulled through the bottom of the column for sixty hours. After addition of a second volume of water, the sample was drained and aerated for five days. A third leaching volume was passed through the column after which the sample was removed, dried, crushed, and finally returned to the column for a fourth volume of leaching water.

CHAPTER IV

WATER QUALITY AND ITS RELATIONSHIP TO SPOIL CHARACTERISTICS

The discharge and water quality data collected at the Edna Mine allow a detailed analysis of the water quality to be made. Observed water quality is examined in terms of the climate, hydrologic system, and physical-chemical characteristics of the geologic material present. The total quantity of salts discharged in the streams from the mine watersheds is computed along with the net inflow of salts in the reach of Trout Creek bordering the western edge of the mine.

Chemical Characteristics of Mine Drainage

Ion Concentration

Detailed chemical analyses were performed on monthly water samples taken at the water quality monitoring stations. From these analyses the average ion concentrations in Table 4-1 and the maximum ion concentrations in Table 4-2 were determined. The recommended drinking water standards of the U. S. Public Health Service (1962) are listed in each table for comparison.

The quality of water from the mine watersheds is generally low due to high concentrations of total dissolved solids. Although not listed in Table 4-1, the average dissolved solids concentrations at Stations C9 and C10 exceed the 500 mg/ℓ standard by two to four times. Water from a subsurface seep at Station C7 displayed the lowest quality with an average dissolved solids concentration of 3838 mg/ℓ and a maximum of 4870 mg/ℓ .

The average water quality of Trout Creek is within the standards. However, there is considerable degradation in quality as Trout Creek flows north adjacent to the mine. The water flowing through Station C2

Table 4-1

Average Ion Concentrations of Monthly Water Samples Taken October 1973 to November 1975

	pH	Hardness total $CaCO_3$ mg/ℓ	Specific Cond. μmohs/cm	Total Dissolved Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe diss. mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
U.S. Drinking Water Standards	-	-	-	500	-	-	250	1.0	0.30	-	-	0.05	-	0.05	250	5.0
Station C1 Trout Creek	7.8	117	175	128	<0.7	37	<1.0	<1.0	<0.07	1.4	9.7	<0.02	3.3	<0.10	19	<0.014
Station C2 Trout Creek	7.8	112	180	119	<0.7	33	<1.0	<1.0	<0.06	1.2	9.2	<0.02	3.3	<0.10	17	<0.016
Station C3 Mine Drainage	7.7	1502	2294	2194	<0.7	392	3.5	<1.0	<0.09	4.0	139	0.20	19.6	<0.10	1075	<0.039
Station C4 Trout Creek	7.9	231	336	261	<0.7	72	1.2	<1.0	<0.06	1.9	21.3	<0.02	5.7	<0.10	90	<0.011
Station C5 Mine Drainage	7.8	2577	3299	3228	<0.7	353	4.5	<1.0	<0.05	17.4	249	<0.02	111	<0.10	1997	<0.015
Station C6 Trout Creek	7.8	235	367	271	<0.7	74	1.2	<1.0	<0.07	2.1	21.1	<0.03	7.7	<0.10	80	<0.012
Station C7 Ground Water	7.5	2039	4416	3838	<0.7	314	8.1	<1.0	<0.07	12.8	173	<0.03	553	<0.10	784	<0.012
Station C8 Trout Creek	7.8	217	413	292	<0.7	70	1.3	<1.0	<0.07	2.3	20.9	<0.03	9.1	<0.10	115	<0.015

Table 4-2

Maximum Ion Concentrations of Monthly Water Samples Taken October 1973 to November 1975

	high / low pH	Hardness total $CaCO_3$ mg/ℓ	Specific Cond. μmohs/cm	Total Dissolved Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe diss. mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
U.S. Drinking Water Standards	-	-	-	500	-	-	250	1.0	0.30	-	-	0.05	-	0.05	250	5.0
Station C1 Trout Creek	8.5 / 7.2	240	249	170	<0.7	51	1.7	<1.0	<0.10	3.6	13	<0.05	4.2	<0.16	130	0.043
Station C2 Trout Creek	8.3 / 7.0	270	261	170	<0.7	54	2.0	<1.0	0.13	3.6	13	<0.05	4.2	<0.20	82	0.057
Station C3 Mine Drainage	8.4 / 6.0	3700	2900	2530	<0.7	480	6.0	<1.0	0.29	13.0	190	0.42	29	<0.20	1700	0.11
Station C4 Trout Creek	8.5 / 7.4	470	853	690	<0.7	210	2.0	<1.0	0.10	5.6	52	0.05	14	<0.16	230	0.017
Station C5 Mine Drainage	8.4 / 6.4	5500	4220	4160	<0.7	440	10.0	<1.0	<0.10	31	320	<0.05	250	<0.16	2500	0.038
Station C6 Trout Creek	8.6 / 6.9	550	840	590	<0.7	190	2.0	<1.0	0.10	9.8	47	<0.05	13	<0.16	208	0.025
Station C7 Ground Water	8.3 / 6.0	3800	5360	4870	<0.7	470	10.0	<1.0	0.14	25.2	250	0.26	1099	0.20	2010	0.020
Station C8 Trout Creek	8.5 / 6.75	540	1150	820	<0.7	210	2.2	<1.0	0.15	18	63	0.06	18	<0.20	480	0.024

is low in total dissolved solids averaging 119 mg/ℓ . The one underground coal mine between Stations C1 and C2 seems to have no effect on water quality which actually improves slightly from Station C1 to C2. The average quality in Trout Creek is reduced at Stations C4 and C6 until it averages 292 mg/ℓ dissolved solids at Station C8. A greater variation in the quality of Trout Creek is found when maximum dissolved solids concentrations are examined. The maximum found at Station C2 is 170 mg/ℓ and the maximum at Station C8 is 820 mg/ℓ .

Most average concentrations of individual ions are below drinking water standards. High average sulfate concentrations are found in water from the mine watersheds and the average manganese concentration at Station C3 exceeds the standard by four times. Some water samples were analyzed for the various heavy metals shown in Table 4-3. Such detailed determinations were not made on water samples from Stations C9 and C10. The number of observations and number of times standards were exceeded pertain to water samples from Stations C3, C5, and C7. These three stations monitor mine drainage with C3 and C5 located on streams and C7 located on a groundwater seep at the base of the spoils along Trout Creek.

The high sulfate and manganese concentrations in Edna Mine drainage may be fairly typical of Colorado. Wentz (1974) noted in examining water samples from throughout Colorado that, of thirty sites sampled, sulfate exceeded the 250 mg/ℓ standard 53.3 percent of the time. He also noted that dissolved manganese is naturally high in Colorado streams. The reason for the high manganese concentrations at Station C3 is not presently known. It is possible that natural concentrations are higher

Table 4-3

Heavy Metals Standards* and Number of Times Exceeded at Stations C3, C5, and C7.

	Standard		#Observations	#Exceeded
Arsenic (As)	0.01	mg/ℓ	19	0
Barium (Ba)	1.0	mg/ℓ	-	-
Cadmium (Cd)	0.01	mg/ℓ	22	1
Chromium (Cr)	0.05	mg/ℓ	18	0
Copper (Cu)	1.0	mg/ℓ	82	0
Iron (Fe diss)	0.3	mg/ℓ	83	2
Mercury (Hg)	0.002	mg/ℓ	24	0
Manganese (Mn)	0.05	mg/ℓ	67	30
Lead (Pb)	0.05	mg/ℓ	15	0
Selenium (Se)	0.01	mg/ℓ	18	10
Zinc (Zn)	5.0	mg/ℓ	71	0

*1962 U.S.P.H.S. Drinking Water Standards.

in the older spoils on the C3 watershed or that a significant time delay is involved before manganese is released by weathering processes.

The ionic composition of water can be examined graphically by plotting the major cation and anion concentrations in milliequivalents per liter. Concentrations in milliequivalents per liter are found by multiplying milligrams per liter by the reciprocal of the combining weight of the ion. The ionic composition of water at Stations C2, C3, C5, and C8 is plotted in this manner in Figures 4-1, 4-2, and 4-3 for January, May, and September, 1975 respectively. These particular months were chosen to illustrate the chemical composition during two low flow periods in January and September, and a high flow period from spring runoff in May. Cations are plotted on the left half of each bar and anions on the right half. If all ions are correctly determined, the total milliequivalents per liter of the cations will equal that of the anions.

The concentration and composition of water at Station C2 varies only slightly over the three months considered. However, the ion concentrations at Station C8 increase significantly in May primarily due to calcium, magnesium, and sulfate ions. These ions can result from the solution of hydrous sulfates such as gypsum ($CaSO_4 \cdot 2H_2O$) and epsomite ($MgSO_4 \cdot 7H_2O$) which are probably found in the rocks of the Williams Fork Formation. The composition of water at Stations C3 and C5 remains relatively constant over the three months considered with the greatest proportion of dissolved solids coming from calcium and magnesium sulfates. Ions other than those shown in Figures 4-1, 4-2, and 4-3 are not considered due to their relatively small concentrations.

Average ion concentrations in Table 4-1 for the same four stations considered above are plotted on a logarithmic scale in Figure 4-4. Note

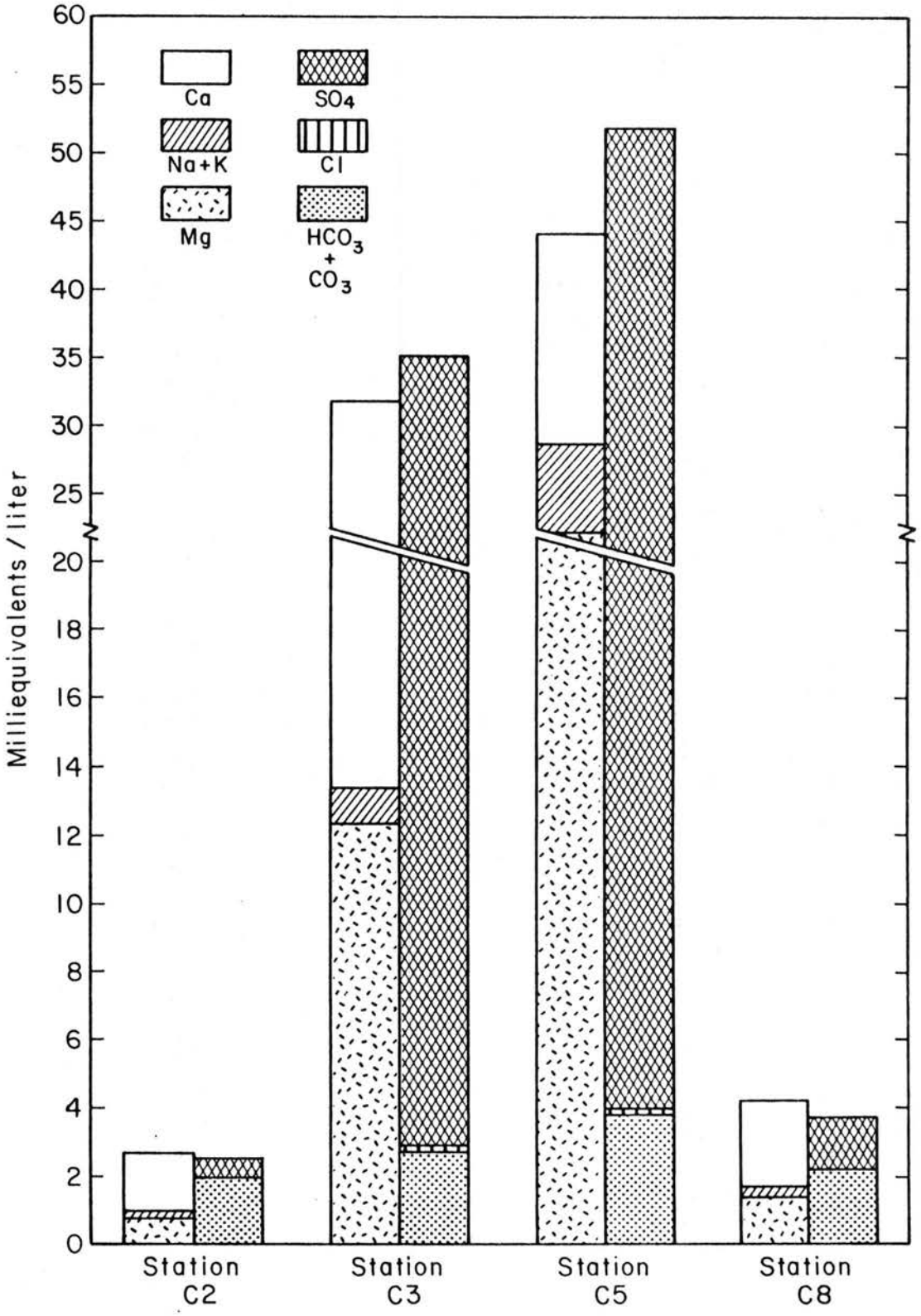

Figure 4-1. Ionic composition of water in January, 1975.

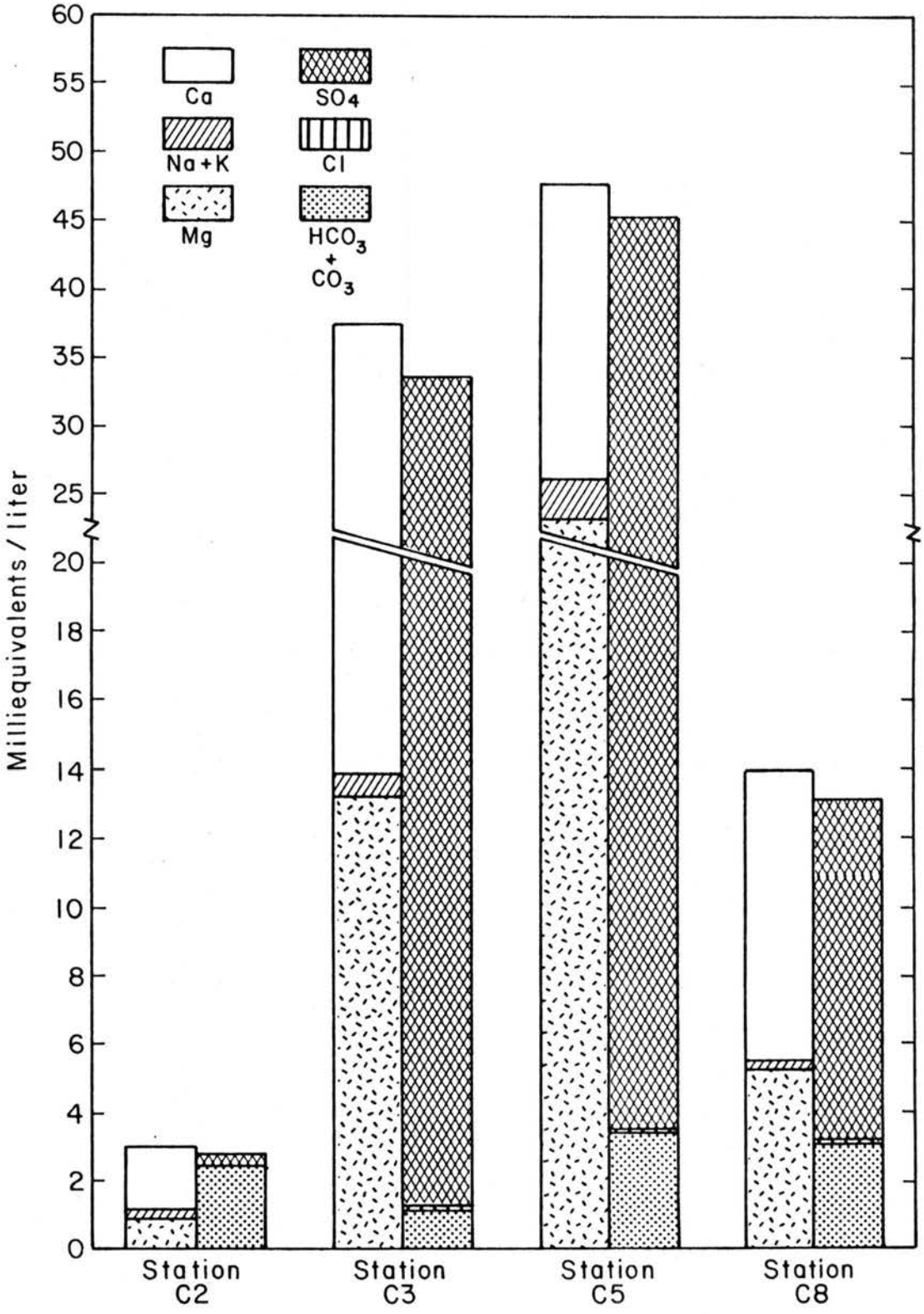

Figure 4-2. Ionic composition of water in May, 1975.

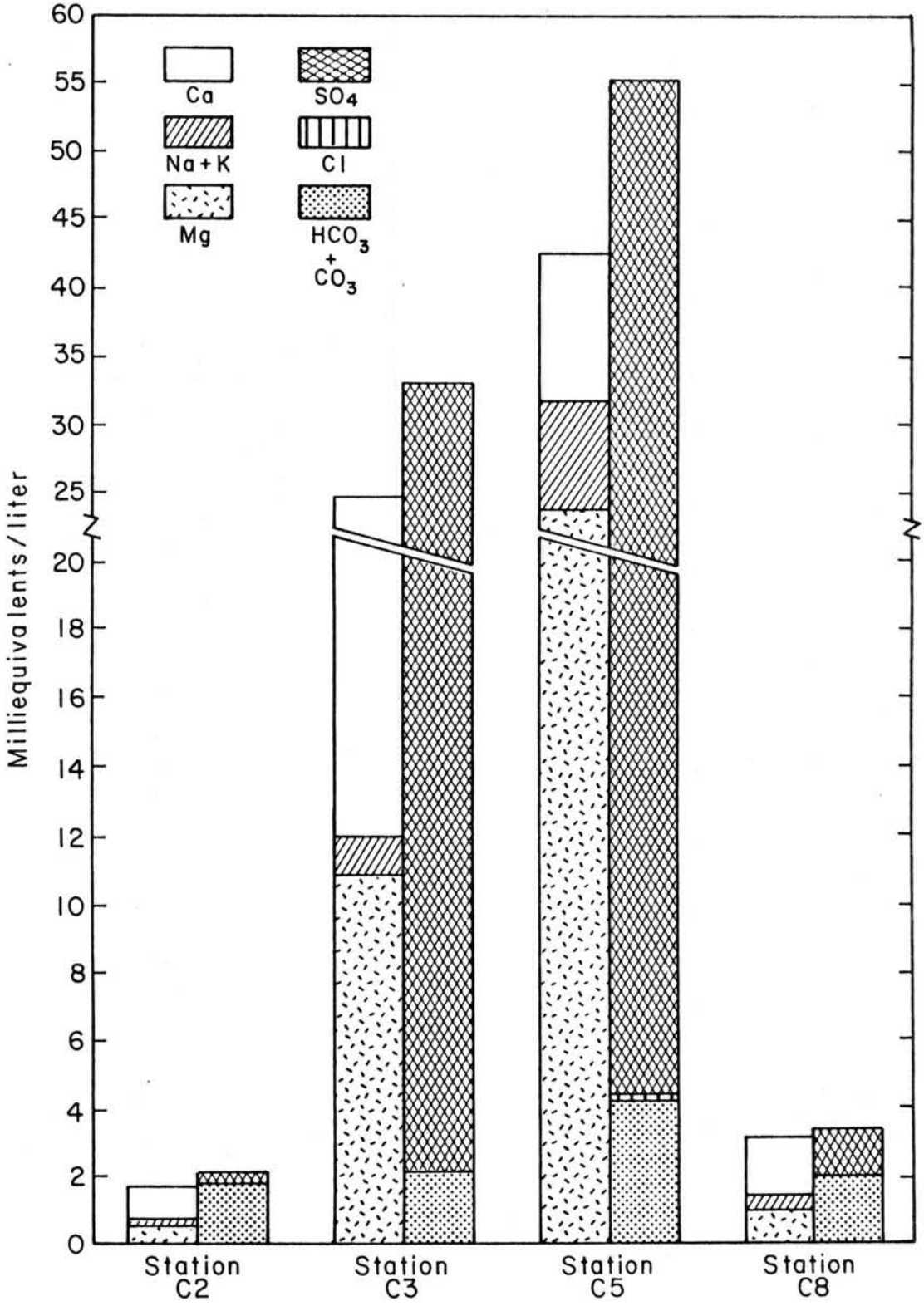

Figure 4-3. Ionic composition of water in September, 1975,

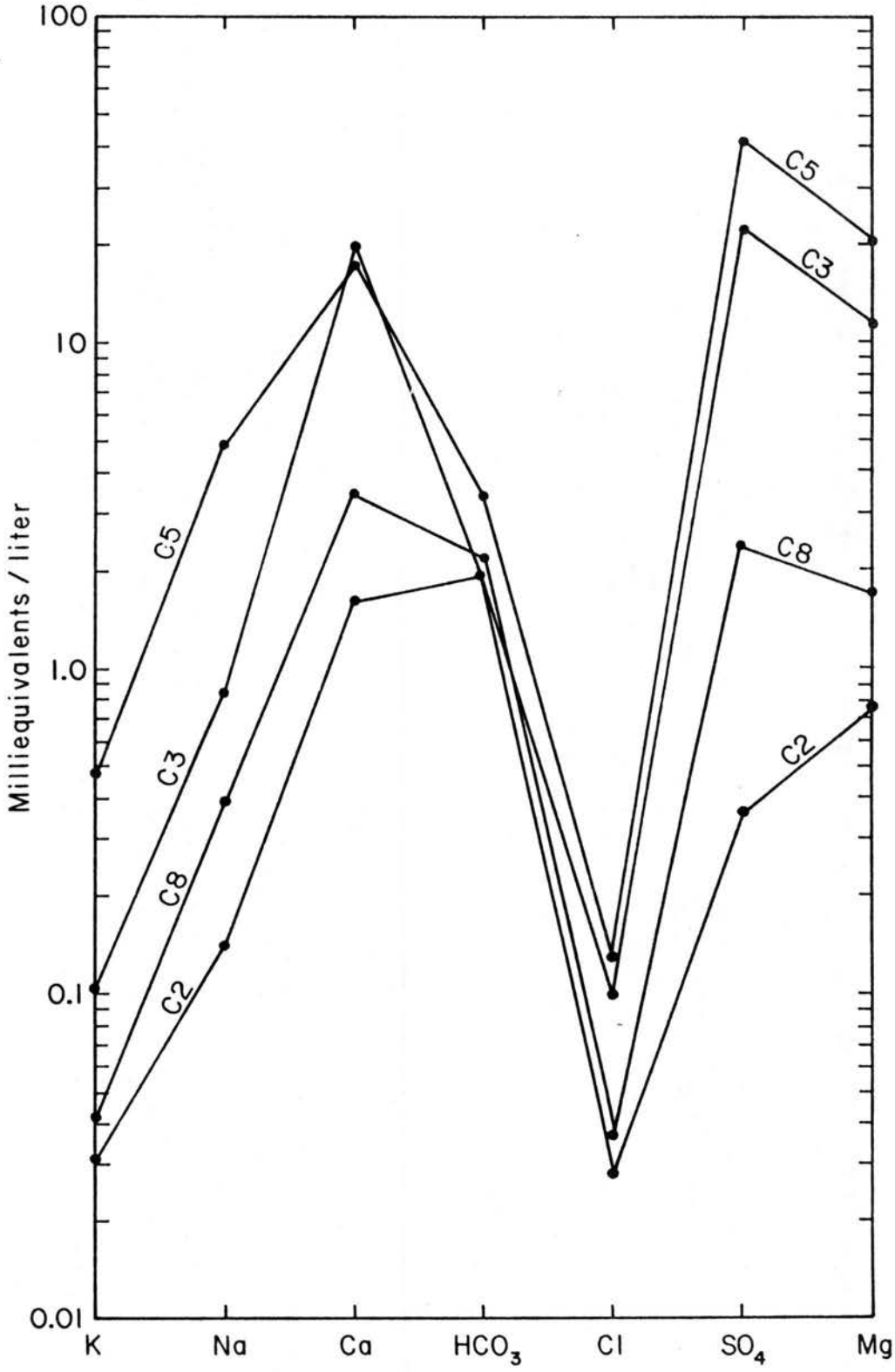

Figure 4-4. Average concentrations of major ions in water from stations shown.

that the amounts of sodium, potassium, and manganese are greater in water from the C5 watershed than that from the C3 watershed. This is expected because of the lower solubility of calcium sulfate, compared to magnesium and potassium salts as previously mentioned. The magnesium and potassium are thus leached to a greater extent from the older C3 spoils while calcium remains about the same in both old and new spoils.

Water quality is degraded in the reach of Trout Creek between Stations C2 and C8 due to the inflow of water containing high concentrations of dissolved solids between these two stations. The amount of degradation attributable directly to mining activity is not readily apparent because the underlying rock formation changes from the Iles above Station C2 to the Williams Fork on the Edna Mine (see Figure 2-2). A natural difference in the potential salt pickup may exist between the two formations which could account for a change in the observed water quality of Trout Creek. No data relating to the pre-mining salt concentrations in Trout Creek and the streams flowing from the mine watersheds is available. Pre-mining salt concentrations must be inferred from post-mining data, therefore. The impact of mining upon the water quality is examined in more detail later in this report.

Estimating Total Dissolved Solids From Electrical Conductivity

Electrical conductivity is a property of water which can be easily measured in the field utilizing a soil moisture bridge apparatus. The ability of water to conduct electricity is related to the concentration of dissolved solids in the water. With a sufficient number of analyses of both the electrical conductivity and total dissolved solids concentration of water samples, a relationship can be developed relating one to the other.

The monthly water samples taken at the Edna Mine provide 102 data points from which the relationship between electrical conductivity at 25°C (specific conductance) and the total dissolved solids concentration can be found. Regression yields a best fit equation of

$$TDS = 0.367\ (EC)^{1.107} \qquad (4\text{-}1)$$

where EC is the specific conductance. A coefficient of determination of $r^2 = 0.989$ is found for the relationship. Most of the data points and the line of best fit determined by equation 4-1 are plotted in Figure 4-5. Equation 4-1 is used to find the total dissolved solids content of samples not subjected to detailed chemical analysis.

Chemical Quality and the Water Cycle

The chemical quality of water changes as it moves through the hydrologic system. Figure 4-6 traces the possible paths available to water movement on a surface mine with conditions similar to those found at the Edna Mine. Impurities present in the atmosphere constitute the first potential source of dissolved solids in water. Precipitation can dissolve these impurities and carry them to the land surface. Overland flow can then dissolve solids from soil and dust particles as it flows to the streams. Both precipitation and overland flow usually have water of better chemical quality than that found in streams.

A substantial portion of precipitation occurring both as rain and snow can infiltrate vertically into the ground and then flow laterally down the dip of the rock strata as groundwater in the saturated zone. This subsurface water can either reappear in streams or leave the watershed as underflow not reappearing as surface runoff. Subsurface water can also flow vertically to deep ground water aquifers if no impermeable boundary exists. Subsurface water possesses a high potential for

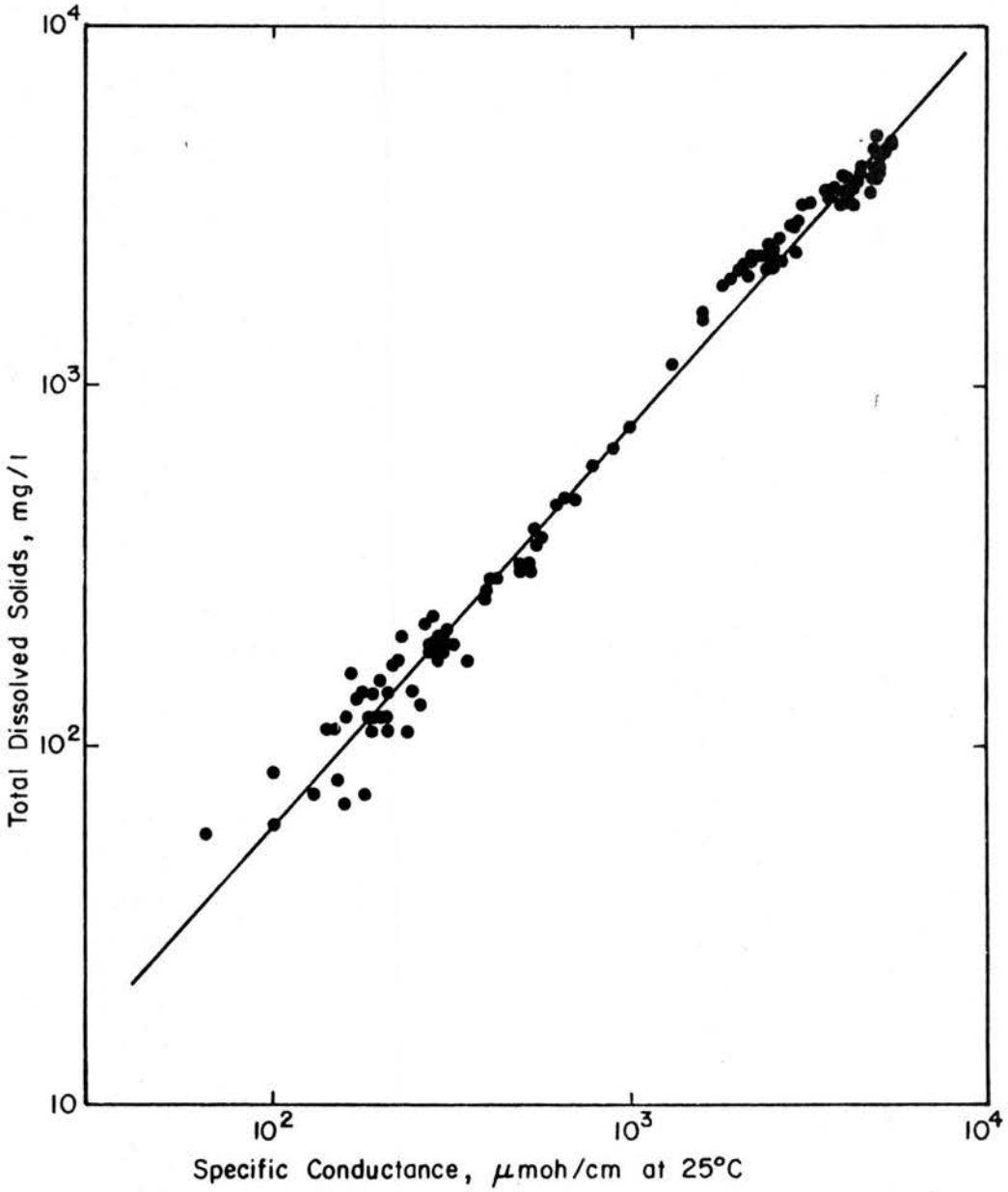

Figure 4-5. Plot of specific conductance versus total dissolved solids for water at the Edna Mine with line of best fit.

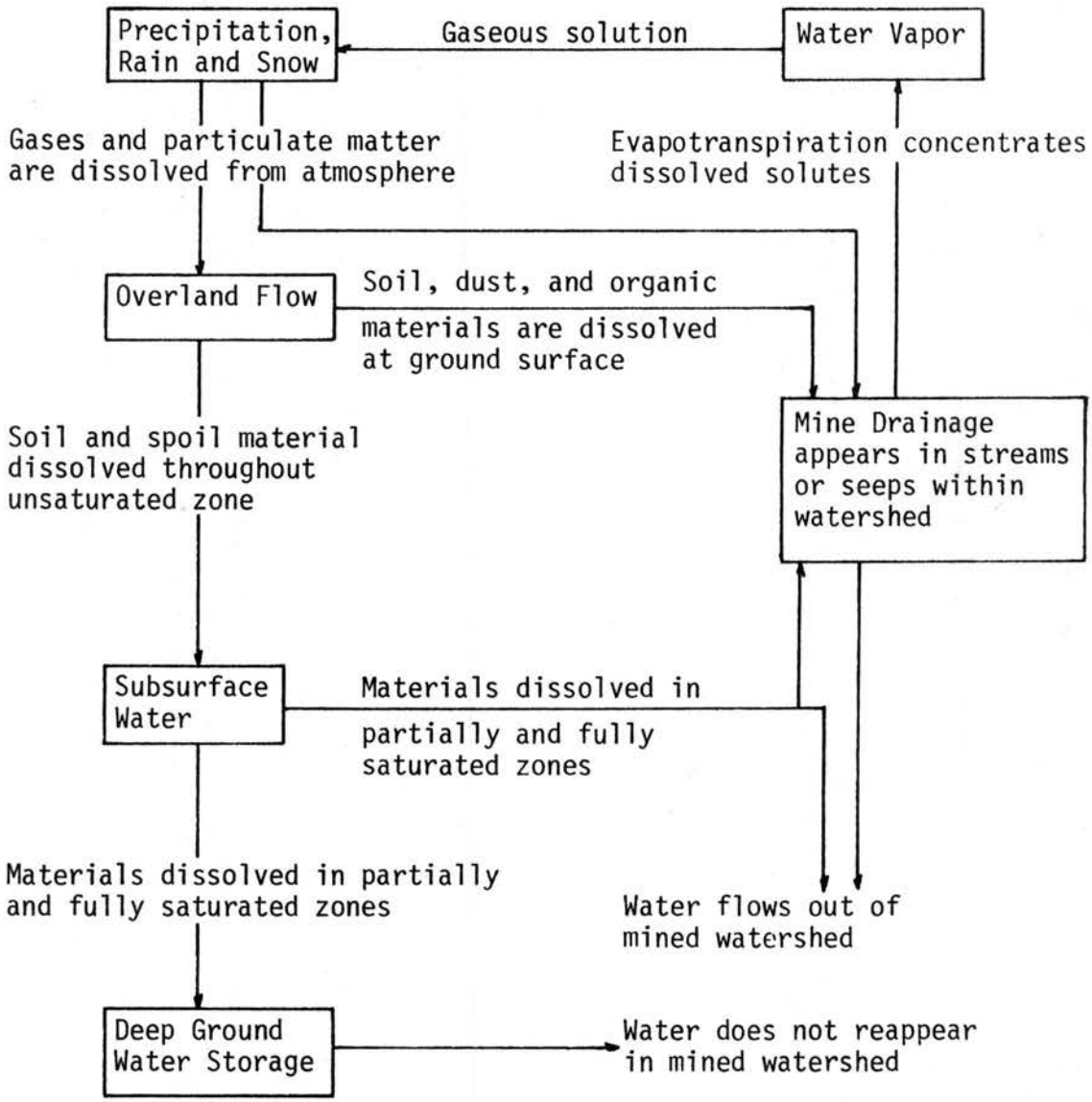

Figure 4-6. Sources of dissolved solids in the hydrologic system on a mined watershed.

acquiring dissolved solids from soil and rock strata and thus its quality is generally reduced relative to that of the average in the stream.

At the Edna Mine about one-half of the precipitation occurs as snow fall which, as it melts, reaches the streams by overland and subsurface flow. It is assumed that underflow, that portion of shallow subsurface water not flowing through the discharge monitoring stations, and deep percolation to underlying aquifers are not important on the Edna Mine because of physical conditions previously discussed. The total stream flow reflects a combination of high quality overland flow and lower quality subsurface flow. During heavy spring runoff natural stream flow should exhibit lower dissolved solids concentrations due to large volumes of high quality overland flow. Trout Creek measured at Station C2 displays this type of behavior as seen in the 1975 discharge and water quality hydrograph in Figure 4-7. Trout Creek measured at Station C6 varies from the behavior at Station C2 as evidenced by the high dissolved solids concentrations during April and May in Figure 4-8.

The 1975 discharge and water quality hydrographs of the streams flowing from the mine watersheds (Figures 4-9, 4-10, and 4-11) show a rise in dissolved solids during spring runoff rather than the expected decline. This indicates very little overland flow and large quantities of subsurface flow of reduced quality. The peaks of the dissolved solids hydrographs from the mine watersheds correspond approximately with the peak observed on the Station C6 dissolved solids hydrograph. No such peak is found at Station C2 indicating that the peak is caused by an inflow of dissolved solids between Station C2 and Station C6. Each component contributing to runoff and its influence on water quality is examined in more detail below.

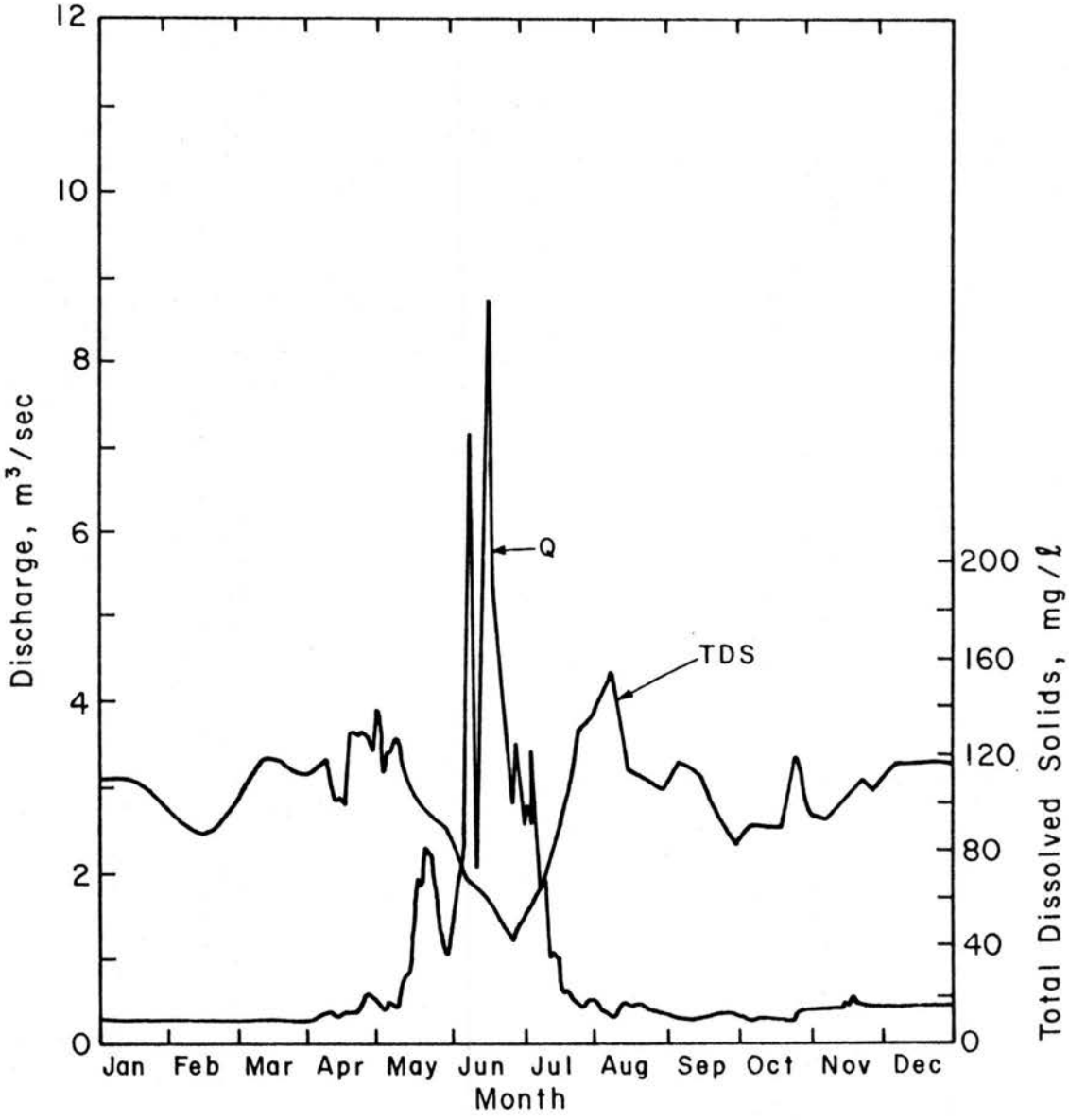

Figure 4-7. Discharge and water quality hydrograph for Station C2, 1975.

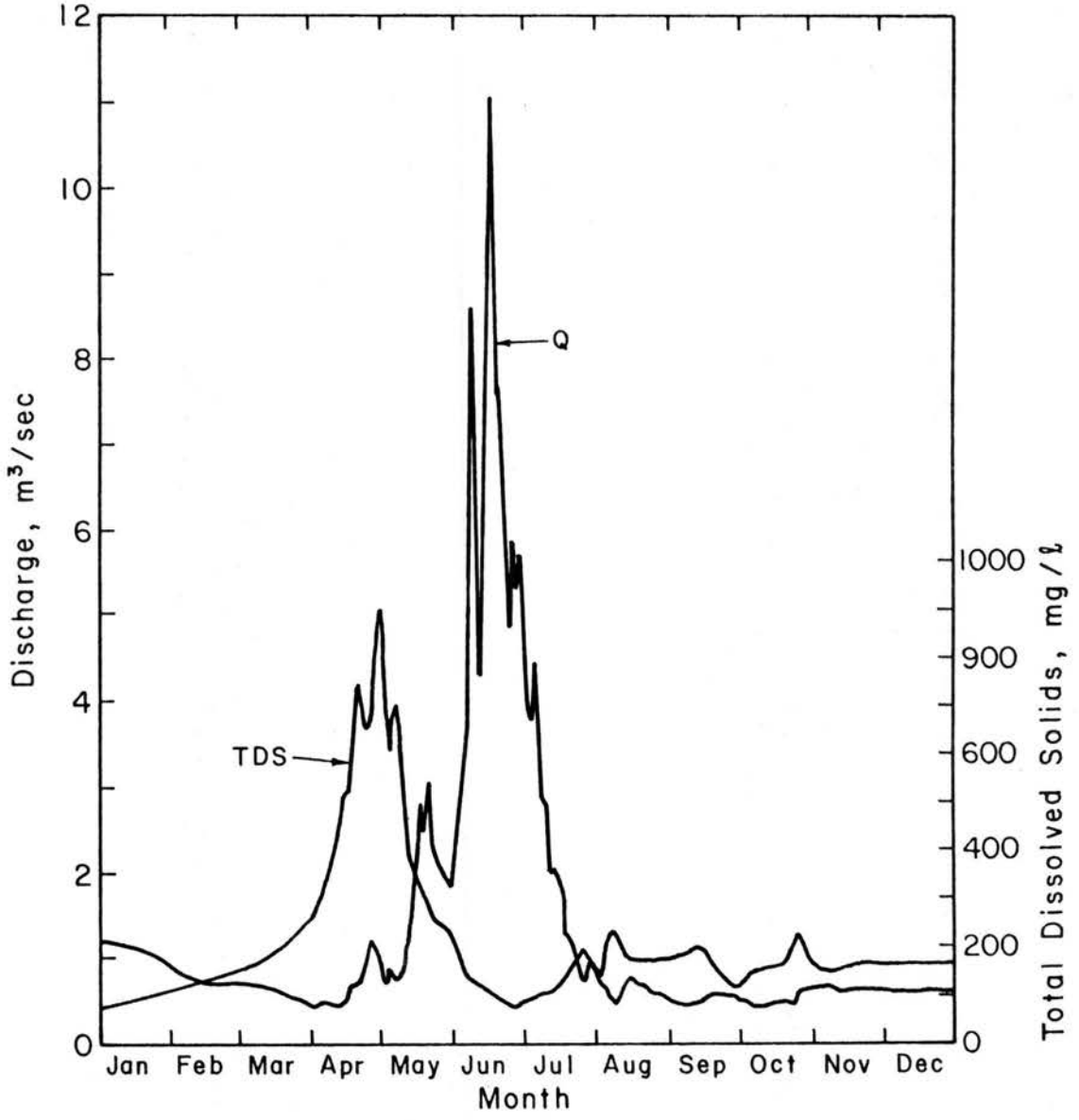

Figure 4-8. Discharge and water quality hydrograph for Station C6, 1975.

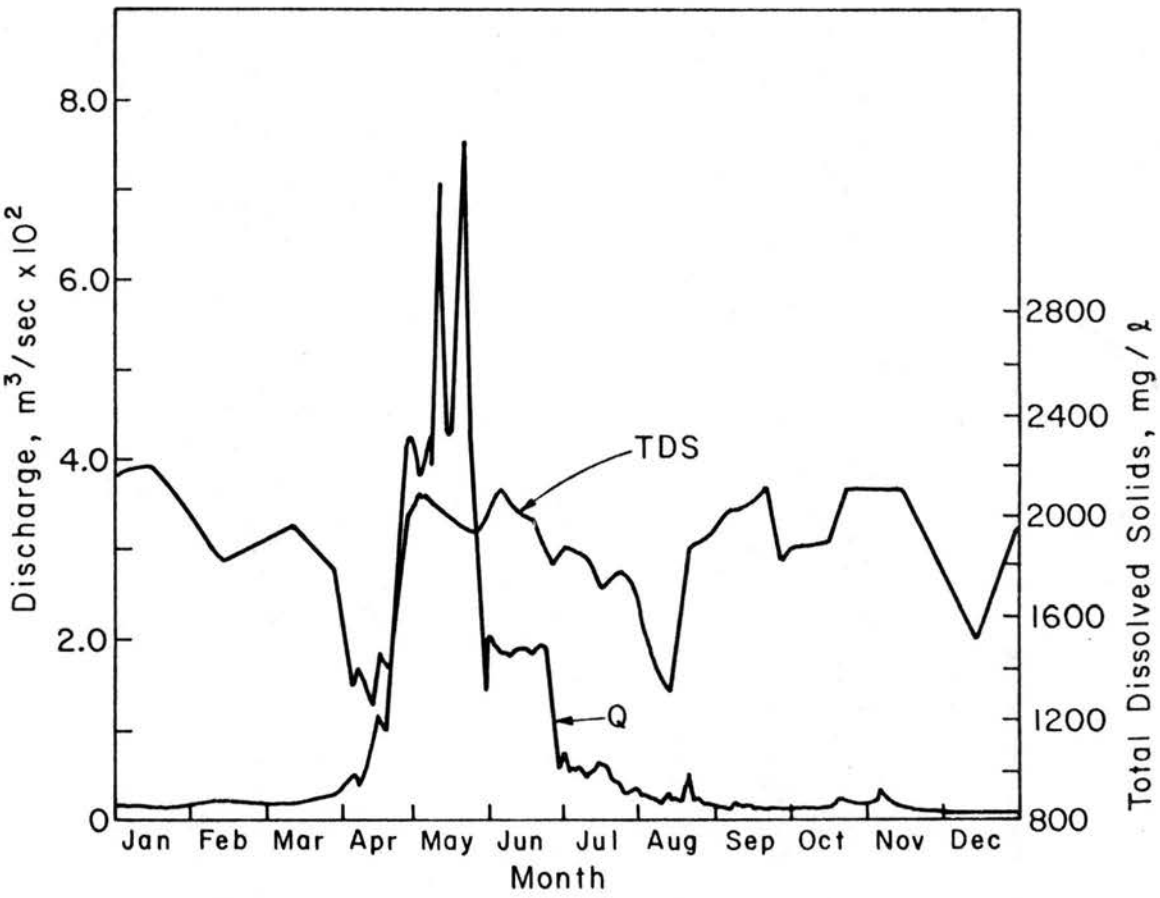

Figure 4-9. Discharge and water quality hydrograph for Station C3, 1975.

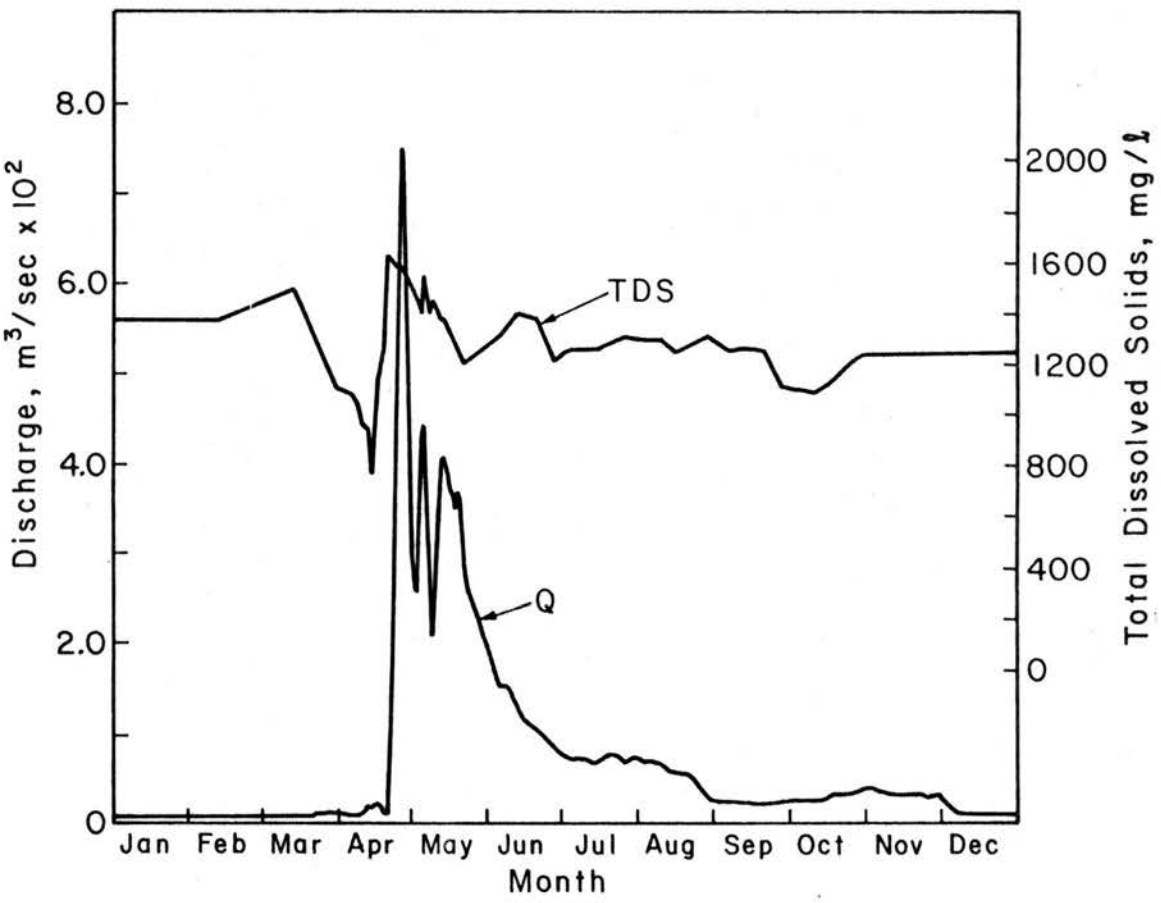

Figure 4-10. Discharge and water quality hydrograph for Station C9, 1975.

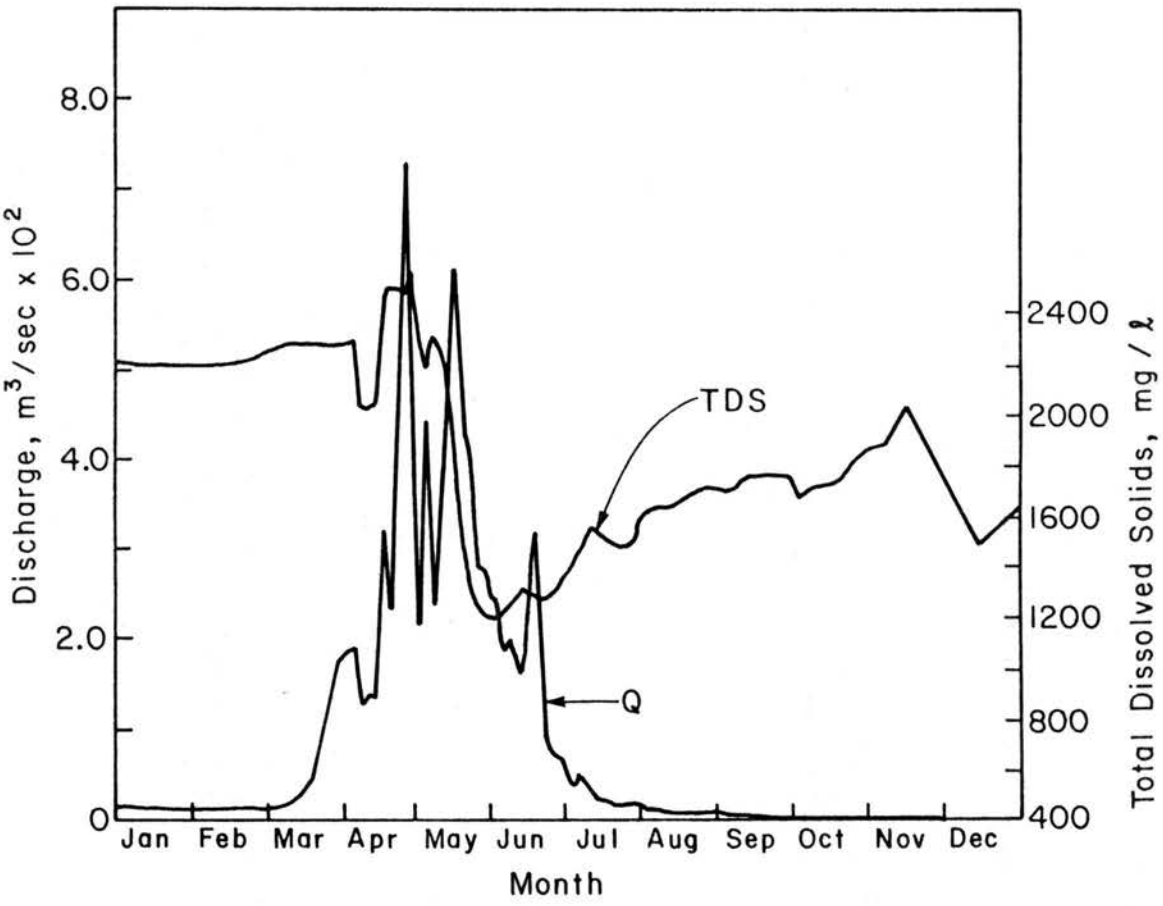

Figure 4-11. Discharge and water quality hydrograph for Station C10, 1975.

Precipitation

Rain and snow dissolve impurities occurring as gases and particulate matter in the atmosphere. These impurities result primarily from fully or partially burned residues and gases discharged into the atmosphere by man's activities. The greatest potential for atmospheric impurities is found near urban and industrial areas with other areas having only small amounts of atmospheric impurities. Precipitation is generally low in dissolved solids. Feth et al. (1964) report conductivities of melted snow in the western U. S. ranging from 2 to 42 micromhos per centimeter. Archer (1968) reports an average dissolved solids concentration of 35 mg/ℓ in the Erie-Niagra Basin but this figure includes industrial and urban areas.

Very little potential for atmospheric pollution currently exists in the region of the Edna Mine with no large industrial or urban areas in close proximity. This situation may change somewhat with the completion and beginning operation of a coal-fired power plant near Hayden about 30 km to the northwest. Although no samples of precipitation were analyzed it is reasonable to assume the concentration negligible when compared with other components of stream flow.

Overland Flow

Overland flow is that part of rainfall or snowmelt which neither seeps into the ground nor evaporates but flows over the land surface until reaching a stream channel. Overland flow contains the dissolved solids of the precipitation plus any additional solutes picked up from the ground surface. The additional gain in dissolved solids is usually small because of rapid leaching of the top layer of surface material. This surface layer of soil or spoils is exposed to sufficient volumes

of water to reduce the quantity of solutes to an amount substantially lower than the layer of soil or spoils immediately beneath the layer on the surface. The leached zone is probably very thin, one centimeter or less in thickness. This is sufficient, however, to protect overland flow from exposure to high concentrations of solutes in the underlying soil or spoils. Due to low precipitation, high potential evapotranspiration, and poor surface drainage, the overland flow component of stream flow is small on the Edna Mine. This observation is substantiated subsequently in this report by the results of model application.

Water samples obtained from the collector troughs after the application of water to the surface of the experimental plots averaged about 246 mg/ℓ total dissolved solids with a standard deviation of σ = 58 mg/ℓ. These samples are probably not an accurate indication of the concentration of overland flow over the entire mine site because the individual plots were often disturbed by roughening, raking, etc.. The irrigation supply used at the plots averaged 192 mg/ℓ (σ = 31 mg/ℓ) which leaves an average net gain of 52 mg/ℓ in overland flow from the plots.

Supplementary surface water samples taken during the spring runoff averaged 149 mg/ℓ (σ = 21 mg/ℓ) on natural land and 158 mg/ℓ (σ = 47 mg/ℓ) on mined land indicating very little difference between concentrations of overland flow from mined and natural land. The surface layer on the spoils is thus leached within several years to a level approximately equal to that of the surface layer on undisturbed ground. A value of 150 mg/ℓ is considered to be the average concentration of overland flow over the entire Edna Mine.

Subsurface Flow

Subsurface flow contributes the largest proportion of water to the total stream flow at the Edna Mine and, therefore, is the major component influencing the concentration of dissolved solids in mine drainage. Spoil piles with their freshly exposed rock material have a large potential for releasing solutes into percolating water, much larger than that of the natural soil and rock strata. The rock forming the spoils contains minerals which have not been exposed to significant volumes of leaching water before mining took place. Within the spoil piles these minerals can now be dissolved by percolating water and carried away. Natural soil has been depleted of salts by continual leaching through time.

Natural portions of the watersheds studied probably have few, if any, ground water aquifers with the possible exception of small alluvial stream channel aquifers. As water percolates into the ground it encounters bedrock forming an impermeable boundary and then flows down dip eventually to reappear in a stream channel. The concentration of subsurface water in the undisturbed areas is estimated from nineteen water samples taken during the base flow period from July 7 to November 7, 1975 at Station C13 to be 462 mg/ℓ (σ = 18 mg/ℓ).

With the destruction of the natural rock strata in the mined areas, water is able to percolate to much greater depths in the spoils before encountering an impermeable boundary or water table. The spoils provide an abundance of soluble salts which are dissolved by leaching waters and carried out of the watershed. Tests conducted at the experimental plots indicate little or no reduction in the salt concentration of leaching water over two years of experiments. Leaching tests discussed later

indicate that weathering probably replaces salts as fast as they are leached under conditions existing at the Edna Mine.

It is believed that most of the subsurface water in the spoils reappears as stream flow within the mine watersheds because of the the highwall forming the western boundary of the spoils. Subsurface water in the area north of the C5 watershed reappears in numerous seeps along the base of the spoils next to Trout Creek (see Figure 2-5). The highwall in this area may act as a dam forming a temporary water table aquifer behind it. If such an aquifer exists, it will fill and then drain during the spring and summer, forming the seeps observed at the base of the spoils as water flows over the top of the highwall or seeps through fractures and permeable rock layers.

The concentration of subsurface water in the spoils varies somewhat with the location and probably the depth. Dissolved solids average 3980 mg/ℓ (σ = 439 mg/ℓ) in 22 water samples taken at Station C7 (Figure 3-1) and 4 samples taken at supplementary Station #23 (Figure 3-2) average 4200 mg/ℓ . An average subsurface water concentration of 3030 mg/ℓ (σ = 540 mg/ℓ) is found from 57 water samples collected from the subsurface drains on the experimental plots. This value is assumed to be representative of the average concentration of subsurface water for all mined portions even though several locations have higher concentrations, up to 4700 mg/ℓ , and several have lower concentrations, down to 2000 mg/ℓ The C3 watershed displayed consistently lower concentrations of dissolved solids than did the other watersheds on the mine. This may be due to significant leaching of salts in the older C3 spoils or the fact that the area was mined irregularly leaving areas of natural ground which can not be differentiated from the mined area. Data used in

determining the above averages can be found in the appendices of this report.

Soil and Spoil Analysis

Tests conducted on spoils, drill cuttings, and natural soils indicate that dissolved solids concentrations of subsurface water from both mined and natural land can be estimated by saturated paste analysis. Eleven 1973 spoil samples averaged 3130 mg/ℓ (σ = 319 mg/ℓ) disregarding three samples which were extremely low. Five drill cuttings composited from several locations and depths from the same year averaged 2579 mg/ℓ (σ = 482 mg/ℓ). The spoil samples closely approximate the value of 3030 mg/ℓ measured in the subsurface drains and assumed to be the average concentration of subsurface water on the mined land. The average concentration of the drill cuttings is lower perhaps due to the lack of sufficient weathering to release soluble solids.

In 1976, additional spoil samples were obtained with six samples from the older spoils on the C3 watershed averaging 2500 mg/ℓ (σ = 337 mg/ℓ) and three samples on the newer spoils north of the C5 watershed averaging 2820 mg/ℓ (σ = 660 mg/ℓ). Eleven samples taken on undisturbed ground averaged 378 mg/ℓ (σ = 271 mg/ℓ), somewhat lower than the estimated subsurface water concentration on undisturbed ground of 462 mg/ℓ . The concentration of 462 mg/ℓ estimated from the C13 watershed may be higher due to small but significant amounts of high concentration subsurface water flowing from within the rock strata along fractures or permeable layers. Evidence of subsurface water in the bedrock is found along a highway cut on the C13 watershed where seeps can be seen in some rock layers during the spring. This deeper subsurface water is not characterized by the soil samples taken on the undisturbed land.

An effort was made to obtain a sample of the surface layer at each of the 1976 sample sites and relate the saturated paste concentrations to that of the surface water. Analyses yielded concentrations ranging from 129 mg/ℓ to about 1000 mg/ℓ . The wide range of values is probably the result of "contaminating" the surface sample with material from beneath the top layer. A more careful sampling procedure, obtaining only the top one or two centimeters of soil, may be useful in estimating the concentration of surface water. However, data from the 1976 soil samples is not used for this purpose.

Leaching Potential

Leaching tests conducted on a composite spoil sample from the experimental plots indicate large quantites of solids available to leaching waters. Results of the leaching test described in Chapter III are plotted in Figure 4-12. The original concentration of total dissolved solids before leaching was 1178 mg/ℓ and this concentration was reduced to 207 mg/ℓ upon the addition of 4260 ml of water. This corresponds to 1.35 meters of water passing through the sample column. After sixty hours of aeration, the initial concentration rose to 318 mg/ℓ and this was reduced to 35 mg/ℓ with a total leaching volume now equal to 7860 ml (2.48 m). The column was again drained and aerated, this time for five days, and the initial concentration rose to 1022 mg/ℓ . This concentration was reduced to 378 mg/ℓ with the total leaching volume equal to 9260 ml (2.92 m). The sample was then dried and crushed and an initial concentration of 371 mg/ℓ was reduced to 53 mg/ℓ with the total leaching volume equal to 12,000 ml (3.79 m).

Previous leaching tests conducted on Edna Mine spoils (McWhorter et al., 1975) indicate that a volume of water equal to about 6.8 times

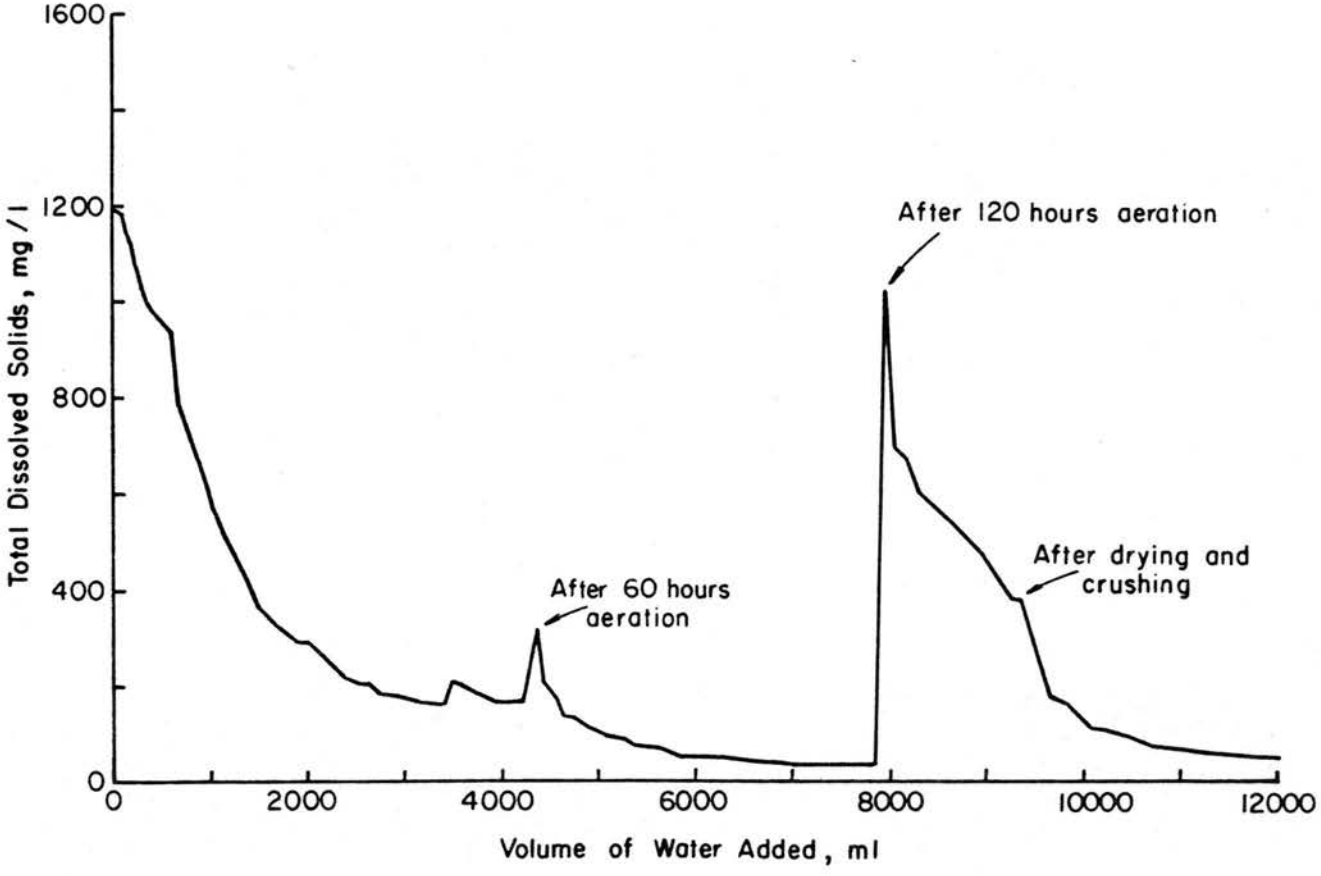

Figure 4-12. Results of leaching test with aeration of sample to produce weathering.

the bulk volume of the sample is needed to reduce the electrical conductivity of the leachate to 5 percent of the original saturated paste conductivity of the sample. Thus, 6.8 cubic meters of water must pass through 1 cubic meter of spoil material to achieve a 95 percent reduction in conductivity. This reduction results in an estimated 2.4 kg/m^3 of salts removed from the spoils. If the spoils are 20 meters in thickness, then 136 m^3 of water per square meter of spoil surface is needed to achieve a 95 percent reduction yielding 48 kg of salts per square meter of spoil area. This estimated salt yield does not include any salts being replaced by the weathering process. If 20 cm of water infiltrates into the spoils annually it would take 680 years to reduce conductivities by 95 percent if weathering is not considered, and longer if weathering is considered. A volume of water equal to twice the bulk volume of the sample will reduce conductivity to approximately 55 percent of the original conductivity. At 20 cm per year infiltration volume, it would still take 100 years to reduce salts to this level again without considering the affects of weathering.

These results indicate that very large volumes of water are required to substantially reduce the amount of solutes in the spoils. Weathering resulting from exposure to air can replenish salts in the spoils to approximately their original levels. This implies that the quantity of percolating water available at the Edna Mine will not significantly reduce the dissolved solids content by leaching for many years. Low precipitation and the capacity for weathering to replace salts will probably serve to keep the concentration of subsurface water at a fairly constant average value for a long period of time.

Observed Discharge and Salt Load

Analysis of Stream Flow Data

Discharge volumes of Trout Creek and three streams flowing from the Edna Mine are determined from staff gage readings and continuous water level recorders. Water levels on the staff gages and recorders placed on the flumes are converted to discharges by using an appropriate equation for free flow conditions in cutthroat flumes developed by Skogerboe et al. (1973). Water levels of Stations C2 and C6 are converted to discharges by using the equations derived from stream gaging data as discussed in Chapter III.

The recorder charts are reduced first by determining the two hour average stages, converting these stages to discharges, and finally averaging the two hour discharges to obtain the average daily discharge. In some instances the recorder data are not usable for several days due to clock stoppage or debris clogging the flumes and stilling wells. The staff gage readings are used to fill in any gaps in the data.

Discharge volumes are not given for Stations C5 and C13 for several reasons. At Station C5 the capacity of the original flume was often exceeded in the spring and little usable data were obtained. Only several months of data were obtained from the larger flume installed in 1976. Discharge volumes at Station C13 are not considered important for this study because no portion of the C13 watershed is mined. Less than one year of discharge data was obtained at Station C13.

Mean daily discharge can be easily found at Station C2 from the recorder data. However, Station C6 was measured at only one point in time, about once every two days at the most. Several simple methods are used to determine the average daily discharge at Station C6 from data

taken at the other discharge stations. Most staff gage readings at Station C6 were taken during or shortly after the Station C2 hydrograph was at a fairly constant minimum value for three to five hours. The change in channel storage can, therefore, be considered equal to zero at that particular time and no routing procedure is used.

It is assumed that the inflow between Stations C2 and C6 for a particular time period is equal to the difference in measured discharge at that time.

$$I(t) = Q_6(t) = Q_2(t) \tag{4-2}$$

where $I(t)$ is the inflow at time t and $Q_6(t)$ and $Q_2(t)$ are the discharges at Stations C6 and C2 at time t. The mean discharge at Station C2 for the two hour period preceeding the measurement at Station C6 is used. Thus, t actually represents this time period. The combined discharge at Stations C3, C9, and C10 is assumed to be directly proportional to the total inflow.

$$I(t) = K[Q_{10}(t) + Q_9(t) + Q_3(t)] \quad , \tag{4-3}$$

where $Q_{10}(t)$, $Q_9(t)$, and $Q_3(t)$ refer to the discharge at Stations C10, C9, and C3 at time t. K is a proportionality constant assumed to be invariant during the day such that the mean inflow is proportional to the sum of the mean daily discharges at Stations C10, C9, and C3.

$$I_M = K(Q_{10M} + Q_{9M} + Q_{3M}) \quad . \tag{4-4}$$

The subscript M refers to the mean values. The mean daily discharge at Station C6 can now be found by adding the mean daily inflow to the mean daily discharge at Station C2.

$$Q_{6M} = Q_{2M} + I_M \quad . \tag{4-5}$$

During much of the year, excluding the period of spring snowmelt, the inflow remains relatively constant for the entire day. This allows the mean daily discharge at Station C6 to be estimated by the equation

$$Q_{6M} = \frac{Q_6(t) \cdot Q_{2M}}{Q_2(t)} \quad . \tag{4-6}$$

Equation 4-6 will yield the same result as using equations 4-2 through 4-5 if inflow is constant over the entire day.

Monthly discharge volumes are tabulated along with monthly salt loads and average monthly total dissolved solids concentrations in Table 4-4. Water volumes are given in units of hectare-meters or hectare-centimeters which can be converted to cubic meters by the factors 1 ha-m = $10^2 m^3$ and 1 ha-cm = $10^4 m^3$. The determination of the salt loads and average dissolved solids concentrations is discussed in the next section.

Discharge volumes in Table 4-4 are divided by the area of the watershed contributing to stream flow to give total runoff in terms of centimeters per year over the entire watershed area as shown in Table 4-5. The combined surface and subsurface runoff in 1975 from the three mine watersheds ranges from 14.4 cm on C3 to only 5.3 cm on C10. This indicates varying amounts of water lost by evapotranspiration or flow not measured at the discharge stations. Errors in delineating the watershed areas will also change the calculated runoff values in Table 4-5. This is especially true on the C10 watershed where surface divides have been destroyed by mining. There is also some uncertainty in determining the groundwater divides which can lead to an error in the calculated values of runoff.

Table 4-4

Monthly Discharge Volumes, Salt Loads, and Average Dissolved Solids Concentrations

Month	Year	Station C6			Station C2			Inflow			Station C3			Station C9			Station C10		
		Q_w (ha-m)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)	Q_w (ha-m)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)	Q_w (ha-m)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)	Q_w (ha-cm)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)	Q_w (ha-cm)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)	Q_w (ha-cm)	Q_{ds} ($kgx10^{-3}$)	P_a (mg/ℓ)
Nov	1973	-	139	181	77	80	104	-	59	-	66.1	15	2269	-	-	-	-	-	-
Dec	1973	-	313	243	129	155	120	-	158	-	60.5	13	2149	-	-	-	-	-	-
Jan	1974	-	182	188	97	116	120	-	66	-	68.3	14	2050	-	-	-	-	-	-
Feb	1974	-	182	303	60	83	138	-	99	-	56.6	10	1767	-	-	-	-	-	-
Mar	1974	-	372	517	72	114	158	-	258	-	75.8	13	1715	-	-	-	-	-	-
Apr	1974	-	411	587	70	90	129	-	321	-	316.0	49	1551	-	-	-	-	-	-
May	1974	-	4650	391	1189	1618	136	-	3032	-	2790.0	577	2068	-	-	-	-	-	-
Jun	1974	-	2650	192	1380	1200	87	-	1450	-	285.0	58	2035	-	-	-	-	-	-
Jul	1974	193	288	149	152	185	122	41	103	251	136.0	26	1912	-	-	-	-	-	-
Aug	1974	167	341	204	121	160	132	46	181	393	68.3	14	2050	-	-	-	-	-	-
Sep	1974	-	204	346	59	86	146	-	118	-	51.3	12	2339	-	-	-	-	-	-
Oct	1974	91	250	275	57	83	146	34	167	491	45.5	11	2418	-	-	-	-	-	-
Nov	1974	95	384	404	81	140	173	14	244	-	58.6	14	2389	-	-	-	-	-	-
Dec	1974	-	241	219	110	179	163	-	62	-	30.3	7	2310	-	-	-	-	-	-
Total	1974	-	10155	-	3448	4054	118	-	6101	-	3981.7	805	2022	-	-	-	-	-	-
Jan	1975	137	273	199	76	83	109	61	190	311	44.4	6.4	1441	49.4	3.1	628	14.8	2.7	1824
Feb	1975	128	160	125	71	62	87	57	98	172	49.4	7.9	1599	49.4	3.1	628	14.8	2.7	1824
Mar	1975	137	259	189	76	91	120	61	168	275	49.4	10.0	2024	30.9	4.3	1392	49.4	11.0	2227
Apr	1975	205	1184	578	118	137	116	86	1047	1217	355.5	57.4	1615	398.7	62.6	1570	589.9	145.2	2461
May	1975	590	2061	349	480	481	100	110	1580	1436	1185.1	233.5	1970	796.2	104.3	1310	974.0	176.1	1808
Jun	1975	1682	1888	112	1435	876	61	248	1012	408	448.1	86.5	1930	307.4	38.5	1252	451.8	57.2	1266
Jul	1975	635	689	109	518	367	71	117	322	275	128.4	23.2	1807	190.1	24.9	1310	80.2	12.5	1559
Aug	1975	193	345	179	126	148	117	67	197	294	50.6	9.9	1957	135.8	18.5	1362	29.6	5.9	1993
Sep	1975	153	249	163	86	89	103	67	160	239	29.6	5.9	1993	50.6	5.6	1107	18.5	3.2	1730
Oct	1975	151	282	175	86	84	98	75	198	264	37.0	7.3	1973	70.4	8.0	1136	16.0	2.8	1750
Nov	1975	138	298	216	126	128	102	12	170	1417	44.4	9.3	2095	70.4	6.4	909	14.8	2.7	1824
Dec	1975	153	265	173	98	118	120	55	147	267	44.4	9.3	2095	70.4	6.4	909	14.8	2.7	1824
Total	1975	4312	7953	184	3296	2664	81	1016	5289	521	2466.3	466.6	1892	2219.7	285.7	1287	2268.6	424.7	1872
Jan	1976	159	240	151	91	86	95	68	154	226	45.5	9.6	2110	3.0	0.4	1333	45.5	9.8	2154
Feb	1976	144	217	151	82	77	94	61	140	230	45.5	8.6	1890	3.0	0.4	1333	45.5	9.5	2088
Mar	1976	224	307	137	114	118	104	110	189	172	52.1	8.0	1536	3.0	0.4	1333	102.3	24.0	2346
Apr	1976	376	1493	397	167	173	104	209	1320	632	449.5	69.8	1553	390.9	46.0	1177	364.7	69.3	1900
May	1976	752	1113	148	552	374	68	201	739	368	277.5	43.6	1571	397.7	48.0	1207	212.7	30.7	1443
Total	1976	1655	3370	204	1006	828	82	649	2542	392	870.1	139.6	1604	797.6	95.2	1194	770.7	143.3	1859

Table 4-5

Total Yearly Runoff (centimeters)

Year	Station C2	Inflow	Station C3	Station C9	Station C10
1974	46.5	-	23.3	-	-
1975	44.5	27.8	14.4	10.9	5.3
1976*	13.6	17.8	5.1	3.9	1.8

*January through May stream flow.

The varying runoff quantities calculated in Table 4-5 may indicate underflow of water from the mine watersheds that is not measured at the monitoring stations. The highwall and trench on the C3 watershed probably catch most of the subsurface runoff. The highwall is not exposed over most of the C9 and C10 watersheds and thus its effectiveness as a barrier to subsurface flow is not known. During the spring of 1975 and 1976, substantial quantities of water were observed flowing from the base of the spoils and entering the C10 stream below the monitoring station. This water was sampled at the supplementary Station #22 and averaged about 2700 mg/ℓ (σ = 187 mg/ℓ). In the spring of 1976, some water from the C10 stream was seen flowing along a road ditch to the C9 stream due to a partially clogged culvert beneath the road. This occurred in the upper reaches of the watershed above most of the disturbed land. It is not known whether the culvert was also partially clogged in 1975 causing a similar loss of water from the C10 watershed during that year. These two water losses from the stream measured at Station C10 may explain the low runoff volumes calculated for the C10 watershed.

The variation in runoff calculated for the three watersheds is probably not the result of changes in storage volumes within the watersheds on an annual basis. When runoff from the C9 and C10 watersheds is taken

as a percentage of that from the C3 watershed, the values remain almost constant with C9 equal to 75 percent and 77 percent at C3 for 1975 and 1976 respectively, and C10 equal to 36 percent and 35 percent of C3 for the same years. The fact that these percentages remain fairly constant from one year to the next indicates that there is little change in storage volume within the watersheds on a yearly basis. This implies a state of dynamic equilibrium in which the total inflow volume of water equals the total outflow volume plus the volume lost by evapotranspiration.

Total runoff of combined surface and subsurface flow over the inflow watershed between Stations C2 and C6 is about 60 percent of the total runoff on the watershed above Station C2 on a per unit area basis. Precipitation in the upper Trout Creek watershed ranges from 75 to 100 cm per year. Thus, the total runoff per unit area above Station C2 is expected to be greater than the total runoff per unit area of the watershed between Station C2 and C6 which receives only about 50 cm of precipitation per year.

Salt Load Calculations

The total quantity of salts discharged from the watersheds on the Edna Mine and the net increase of salts in Trout Creek from Station C2 to Station C6 are calculated from the stream flow and water quality data. Daily discharge and dissolved solids concentrations are multiplied to obtain daily salt loads which are summed to yield the monthly salt loads shown in Table 4-4. The average monthly total dissolved solids concentrations shown in Table 4-4 are found by dividing the monthly salt load by the volume of discharge. During 1974 and several months of 1975 and 1976, the salt load is estimated from only one or, in some months,

several measurements of discharge and concentration. Also during most of 1974 no discharge data is available at Station C6 so the discharge at Station C2 is used to find salt loads at C6 assuming inflow to be zero (McWhorter et al., 1975).

In 1974, 4,054,000 kg of dissolved solids passed through Station C2 and 10,155,000 kg passed through Station C6 for a net inflow of 6,101,000 kg of salts. Of this total 80 percent came in April, May, and June. The totals for 1975 were lower reflecting less runoff with 2,664,000 kg passing through Station C2 and 7,953,000 kg passing through Station C6 for a net inflow of 5,290,000 kg . Of this total 70 percent came in April, May, and June. Partial totals for 1976 show 828,000 kg passing Station C2 and 3,370,000 kg passing Station C6 for a net inflow of 2,542,000 kg by the end of May.

A more graphic representation of the water quality degradation between Station C2 and Station C6 is seen by plotting average monthly dissolved solids concentrations (discharge weighted) from Table 4-4 in Figure 4-13. The concentrations at Station C2 do not vary widely during the year with the highest concentrations occurring during periods of lowest stream flow. The best water quality is found in May and June due to the dilution effect of high quality snowmelt in the upper reaches of Trout Creek.

Concentrations at Station C6 reflect a large inflow of dissolved solids during April and May between Stations C2 and C6. This inflow probably continues into June. However, the increased discharge in Trout Creek results in a lower total concentration at Station C6. The high concentrations observed at Station C6 correspond to the period of snowmelt at the elevation of the Edna Mine. As explained earlier, most of the snowmelt runoff percolates into the ground and increases in

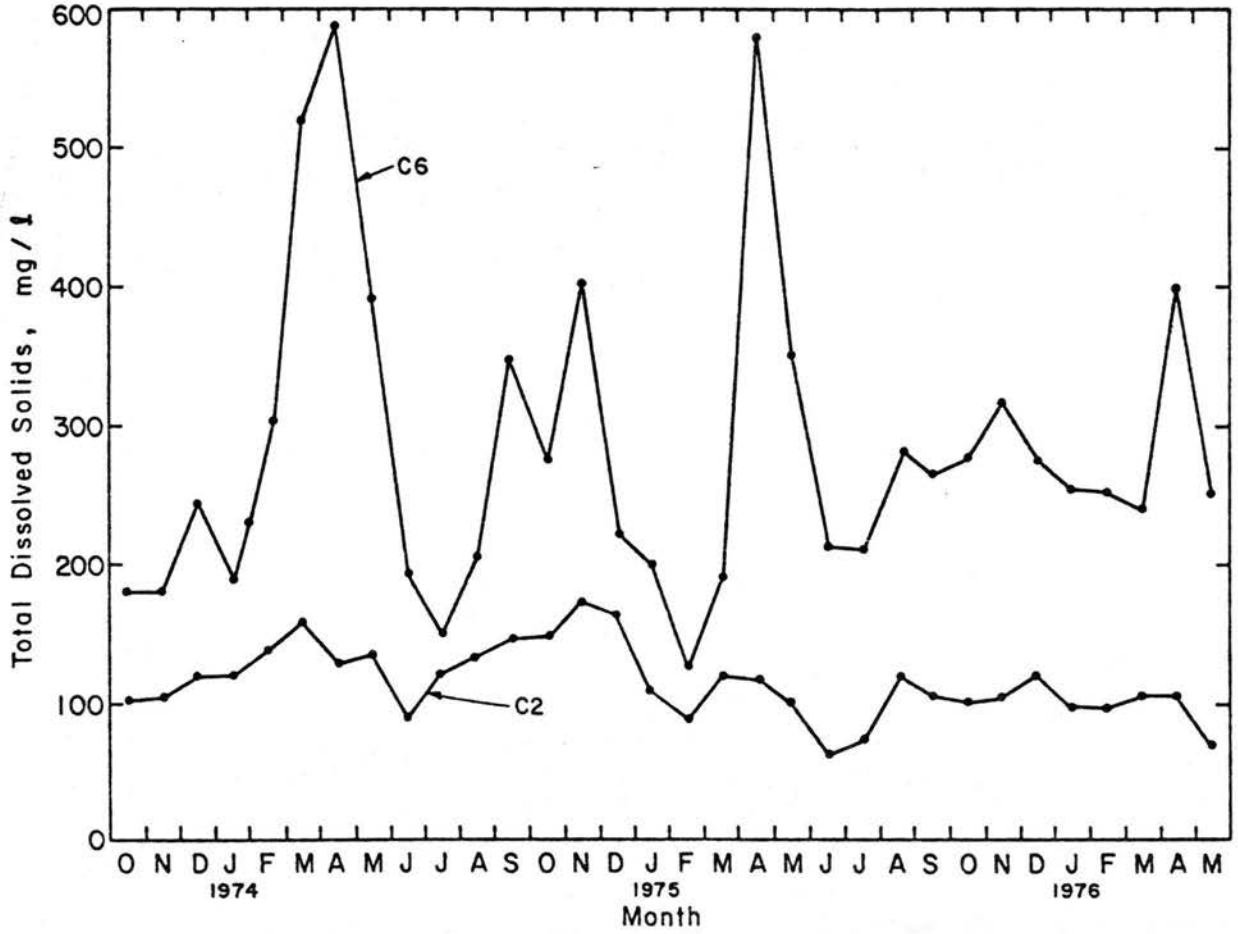

Figure 4-13. Average monthly dissolved solids concentrations for Stations C2 and C6 on Trout Creek (discharge weighted).

concentration before flowing into Trout Creek. Natural subsurface water concentrations (462 mg/ℓ) are sufficiently high to increase the concentration of Trout Creek at Station C6. Therefore, the total increase in the concentration at Trout Creek is not entirely attributable to surface mining.

The annual quantity of salts in Trout Creek increases two to three times between Stations C2 and C6 with most of this increase coming in April, May, and June. With a total inflow of 5,290,000 kg of salts in 1975, only 1,177,000 kg or 22 percent entered from the streams monitored at Stations C3, C9, and C10. In 1976 only 15 percent of total salt load by the end of May is accounted for by these streams. Addition of the salts from Stations C5 and C13 and several small streams on the west side of Trout Creek would increase these percentages, but a substantial amount of salts probably enters Trout Creek from subsurface seeps.

Numerous subsurface water seeps can be seen during the spring and early summer at the base of the spoils along Trout Creek north of the C5 watershed. The water quality of these seeps is very poor but the quantity of salts they discharge into Trout Creek is not known. The volume of water and salts discharged from these seeps could be quite large. The high infiltration capacity and lack of vegetation on the spoils in this area may allow most of the precipitation to percolate into the spoils and reappear at the seeps.

Dissolved solids concentrations can be normalized by dividing the total salts by the total discharge volume to give an average dissolved solids concentration which can be considered as a salt pickup rate. This rate indicates the quantity of salts dissolved per unit area per unit of runoff. Monthly dissolved solids concentrations expressed in

kilograms per hectare per centimeter of runoff are plotted along the solid line in Figure 4-14. Estimates of these values were also made by averaging total dissolved solids concentrations from water samples without using the discharge volume as a weighting factor. The close agreement between the measured and estimated values indicates that discharge monitoring may not be necessary to determine fairly accurate average dissolved solids concentrations on a monthly or yearly basis when total dissolved concentrations remain fairly constant. Average dissolved solids concentrations at Station C5 were determined in this manner because of the lack of discharge data. In general, average concentrations should be weighted with discharge, if possible.

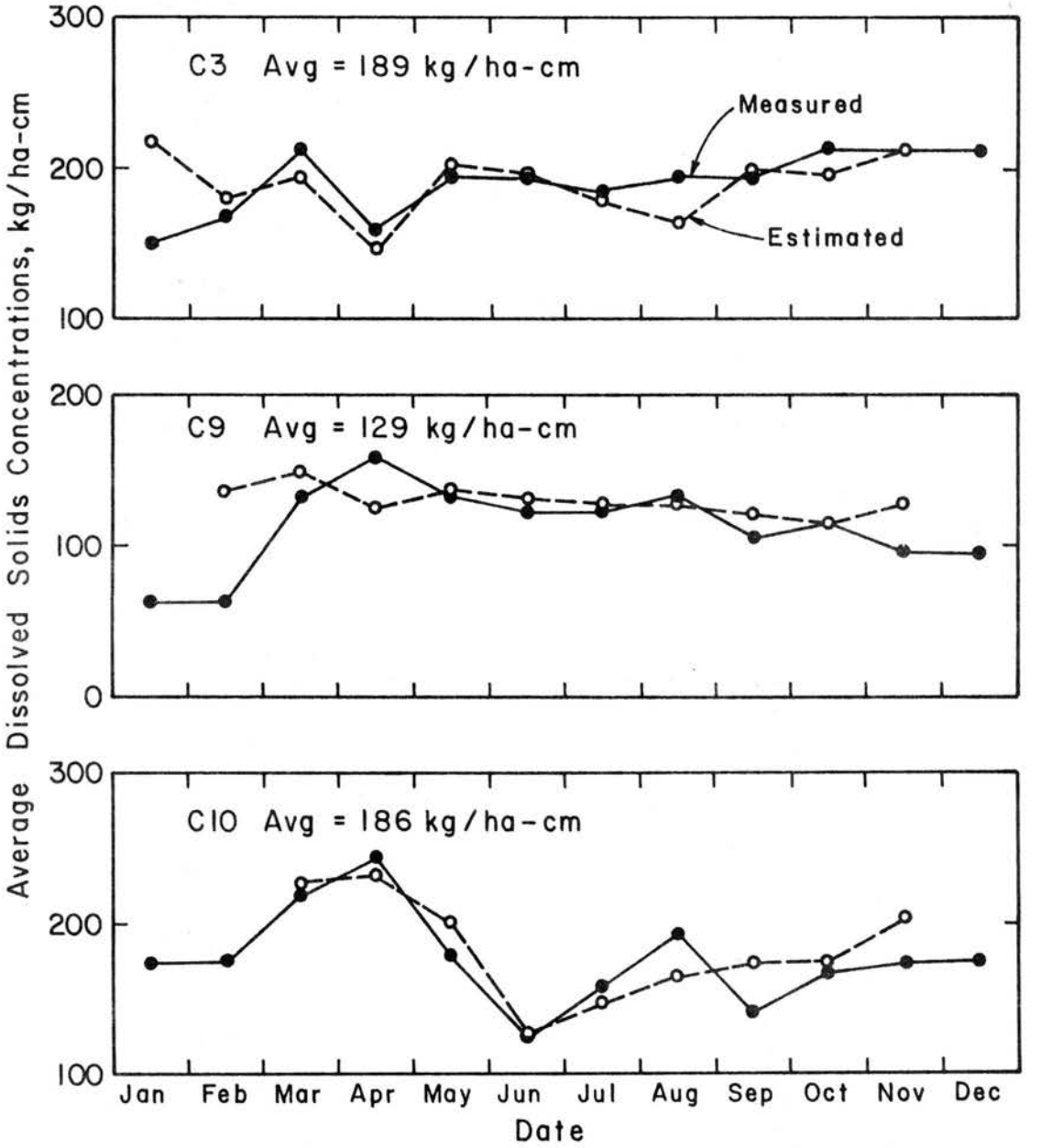

Figure 4-14. Comparison of actual (discharge weighted) and estimated average monthly dissolved solids concentrations.

CHAPTER V

WATER QUALITY MODEL

To meet the future demands for coal large areas of land will have to be surface mined with a resulting potential to adversely affect water resources. A method of evaluating the pollution potential and the effectiveness of various reclamation efforts is needed for the proper planning and management of surface mining. In the Colorado River Basin methods of predicting and controlling salinity are needed if the salt load of the Colorado River is to be maintained at present levels or reduced.

In this chapter a single-equation model is developed which predicts the degradation of water quality due to high concentrations of dissolved solids in mine drainage. The model is derived with respect to conditions found at the Edna Mine and is tested using the data presented in this report. The model should be adaptable to similar surface mines in the western United States which would make it a valuable tool for planning and management.

The model is developed from a combination of water and mass balances written for the mine watersheds. Several investigators have used a similar approach to predict the ground water component of storm runoff and construct a base flow hydrograph.

Pinder and Jones (1969) use a mixing model to predict ground water runoff on three small watersheds in Nova Scotia. They use the equation

$$C_{tr} = (Q_{dr}C_{dr}+Q_{gw}C_{gw})/Q_{tr}$$

where C is the total dissolved solids concentration and Q is the instantaneous discharge. The subscripts tr, dr, and gw refer to total, direct (overland flow), and ground water runoff respectively. Satisfactory results are achieved when the base flow calculated from the

mixing model was compared to that calculated from water levels in observation wells. The concentration of ground water was determined from water samples taken during low flow and the concentration of direct runoff was determined from water samples taken in small streams and rills during periods of very high runoff. Visocky (1969) uses the same approach to predict base flow in the Panther Creek Basin in Illinois and also finds the results satisfactory.

Water Balance

The water balance for a watershed can be expressed as volumes of water per time for each of the components entering into the balance.

$$V_p - V_e - V_s - V_g - V_d = \Delta S \quad , \qquad (5\text{-}1)$$

where

V_p = volume of precipitation per unit time (t),

V_e = volume of evapotranspiration per unit time (t),

V_s = volume of overland flow per unit time (t),

V_g = volume of interflow and groundwater per unit time (t),

V_d = volume of groundwater per unit time (t) that percolates to deep aquifers not contributing to stream flow within the boundaries of the watershed,

ΔS = change in storage volume in the watershed per unit time (t).

It is assumed that over a long period of time, say one year, the change in storage approaches zero. This occurs if the hydrologic system is in a state of dynamic equilibrium where total inflow equals total outflow. As mentioned in Chapter IV, there is evidence for the existence of this condition on the Edna Mine watersheds. This must be considered as an engineering approximation since the watersheds being considered are in the process of being disturbed by mining.

At the Edna Mine V_d is assumed to equal zero due to geologic and hydrologic conditions previously discussed. In many areas conditions are such that significant volumes of water are lost by percolation to deep aquifers in which case V_d must be considered. This component is easily incorporated into the model if the volume of water lost can be estimated.

With ΔS and V_d equal to zero, equation 5-1 can be rearranged so that

$$V_p - V_e = V_s + V_g = V_t \quad , \tag{5-2}$$

where V_t is the total volume of drainage from the watershed per unit time (t).

Now, let A_m be the area disturbed by mining, A_n be the area still undisturbed, and A_t be the total area of the watershed. The subscripts t , m , and n will refer to total, mined, and natural respectively throughout this report. Equation 5-2 can be written as

$$V_t = q_t A_t = q_m A_m + q_n A_n = (q_{pm}-q_{em})A_m + (q_{pn}-q_{en})A_n \tag{5-3}$$

where the subscripts p and e refer to precipitation and evapotranspiration and q represents the volume of water per unit surface area of watershed.

Letting $F_m = A_m/A_t$ and $(1-F_m) = A_n/A_t$ and rearranging equation 5-3 gives

$$q_t = q_m F_m + q_n(1-F_m) = (q_{pm}-q_{em})F_m + (q_{pn}-q_{en})(1-F_m) \tag{5-4}$$

where F_m represents the fraction of the total watershed that is disturbed by mining.

Considering the precipitation to be uniformly distributed over the watershed, then $q_{pm} = q_{pn} = q_p$ and equation 5-4 can be divided by q_p

and written as

$$\frac{q_t}{q_p} = (1 - \frac{q_{em}}{q_p})F_m + (1 - \frac{q_{en}}{q_p})(1-F_m) \quad . \qquad (5\text{-}5)$$

Now, let

$$f_{em} = q_{em}/q_p \quad , \quad f_{en} = q_{en}/q_p \qquad (5\text{-}6)$$

where f_{em} and f_{en} are the fraction of precipitation lost through evapotranspiration from the mined and natural land respectively. Combining equations 5-5 and 5-6 yields

$$\frac{q_t}{q_p} = (1-f_{em})F_m + (1-f_{en})(1-F_m) \quad . \qquad (5\text{-}7)$$

Equation 5-7 states that the unit volume of combined surface and subsurface runoff as a fraction of the precipitation is a function of the fraction of precipitation lost by evapotranspiration on undisturbed and mined land and the fraction of land disturbed by mining. The two factors f_{en} and f_{em} may not be equal due to variations in vegetation, overland flow, infiltration, etc..

Mass Balance

In formulating a mass balance it is assumed that the quantity of soluble solids available to water remains relatively constant in each component contributing to runoff. Thus, over relatively short time periods, (10-50 years) there is no significant change in the quantity of soluble salts being leached from the soil and spoils.

Experiments conducted on the Edna Mine plots indicate that even after repeated applications of water there is no significant reduction in the total dissolved solids content of water flowing from the subsurface drains. Leaching tests indicate that large volumes of water are needed to reduce the electrical conductivity of the spoils even without

any replacement of solutes by weathering. Tests also indicate that weathering can replace solutes as fast as they can be leached by water because of low precipitation and a high capacity in the spoils for releasing soluble salts. It is, therefore, reasonable to assume no change in the amount of soluble salts due to leaching over a long period of years.

With this assumption the mass balance can be expressed as

$$V_t P_t = V_m P_m + V_n P_n \quad , \tag{5-8}$$

where P_t , P_m , and P_n equal the average TDS concentrations over time, t , in drainage volumes from the entire watershed, the mined portion of the watershed, and the natural portion of the watershed, respectively.

Expressed in terms of volumes per unit area, equation 5-8 becomes

$$A_t q_t P_t = A_m q_m P_m + A_n q_n P_n \quad , \tag{5-9}$$

or

$$P_t = \frac{q_m}{q_t} F_m P_m + \frac{q_n}{q_t} (1-F_m) P_n \quad . \tag{5-10}$$

Since $q_m = q_p - q_{em}$ and $q_n = q_p - q_{en}$, equation 5-9 can be written as

$$P_t = \left(\frac{q_p - q_{em}}{q_t} \right) F_m P_m + \left(\frac{q_p - q_{en}}{q_t} \right) (1-F_m) P_n \quad . \tag{5-11}$$

Multiplying by q_p/q_p and using equation 5-6 yields

$$P_t = \frac{q_p}{q_t} (1-f_{em}) F_m P_m + \frac{q_p}{q_t} (1-f_{en})(1-F_m) P_n \quad . \tag{5-12}$$

Combination of Water and Mass Balance

Equation 5-7 can be substituted into equation 5-12 to give

$$P_t = \frac{(1-f_{em}) F_m P_m + (1-f_{en})(1-F_m) P_n}{(1-f_{em}) F_m + (1-f_{en})(1-F_m)} \quad , \tag{5-13}$$

which can be rearranged as

$$P_t = \frac{P_m}{1+\left(\frac{1-f_{en}}{1-f_{em}}\right)\left(\frac{1-F_m}{F_m}\right)} + \frac{P_n}{1+\left(\frac{1-f_{em}}{1-f_{en}}\right)\left(\frac{F_m}{1-F_m}\right)} \quad . \tag{5-14}$$

Two watershed parameters, K and R , are defined as

$$K = (1-f_{en})/(1-f_{em}) \tag{5-15}$$

and

$$R = (1-F_m)/F_m \quad . \tag{5-16}$$

From these definitions it is seen that K is the ratio of combined surface and subsurface runoff from the natural portion of the watershed to that of the mined portion. This means that any factors which influence the evapotranspiration on the two portions of the watershed will also influence K . For example, if runoff is greater on the mined land due to lack of vegetation, then K is less than unity. If evapotranspiration is the same on both mined and unmined portions, then K equals unity. By definition R is the ratio of the area of the natural land to the area of the land distrubed by mining. Thus, R is zero for a completely mined watershed, unity for a fifty percent mined area, and infinity for a watershed with no disturbance from mining.

Substituting K and R into equation 5-14 yields

$$P_t = \frac{P_m}{1+KR} + \frac{P_n}{1+\frac{1}{KR}} \tag{5-17}$$

or

$$P_t = \frac{KP_nR+P_m}{1+KR} \quad . \tag{5-18}$$

Equation 5-18 predicts the concentration of the total runoff from a watershed provided the parameters K and R are known and the average concentrations of flow components from the mined and natural portions of the watershed can be determined.

The concentrations of the surface water and subsurface water from mined and unmined portions of a watershed may each be different. The total amount of dissolved solids from each portion can be written as a sum of surface and subsurface components such that

$$q_m P_m = q_{sm} P_{sm} + q_{gm} P_{gm} \tag{5-19}$$

and

$$q_n P_n = q_{sn} P_{sn} + q_{gn} P_{gn} \quad , \tag{5-20}$$

where the subscripts s and g refer to surface and subsurface respectively. Dividing equation 5-19 by q_m and equation 5-20 by q_n and defining

$$f_{sm} = q_{sm}/q_m \quad , \quad f_{sn} = q_{sn}/q_n \tag{5-21}$$

allows equations 5-19 and 5-20 to be written as

$$P_m = f_{sm} P_{sm} + (1-f_{sm}) P_{gm} \tag{5-22}$$

and

$$P_n = f_{sn} P_{sn} + (1-f_{sn}) P_{gn} \quad . \tag{5-23}$$

The parameter f_{sm} is the fraction of total drainage from the mined land that is overland flow and f_{sn} is the fraction of total drainage from the natural land that occurs as overland flow. Using equations 5-22 and 5-23, equation 5-18 can be written in an expanded form yielding

$$P_t = \frac{KR[f_{sn} P_{sn} + (1-f_{sn}) P_{gn}] + f_{sm} P_{sm} + (1-f_{sm}) P_{gm}}{1+KR} \quad . \tag{5-24}$$

The preceding derivation assumes that there is no chemical interaction, once in the stream, between solutes in the surface and subsurface water so that the average concentration of total runoff, P_m and P_n, can be written as a sum of the two components. The model also assumes that the volume of each component is directly related to the fraction of

land mined. For instance, the model does not allow for significant volumes of groundwater from the natural land to flow underground to the mined land. Adjustments in the model to include this interaction between water from mined and natural land before it appears as streamflow may be possible but are not considered here.

Deep Ground Water Percolation

An additional term must be added to the water quality model if a significant amount of water percolates to deep aquifers and, therefore, does not reappear within the boundaries of the watershed being considered. Addition of a term for deep ground water changes the water balance, equation 5-7, to

$$\frac{q_t}{q_p} = (1-f_{em}-f_{dm})F_m + (1-f_{en}-f_{dn})(1-F_m) \qquad (5\text{-}25)$$

and the mass balance, equation 5-12, becomes

$$P_t = \frac{q_p}{q_t}(1-f_{em}-f_{dm})F_m P_m + \frac{q_p}{q_t}(1-f_{en}-f_{dn})(1-F_m)P_n \qquad (5\text{-}26)$$

where f_{dm} and f_{dn} are the fraction of precipitation lost by deep ground water percolation on the mined and natural land respectively.

A combination of water and mass balances again yields equation 5-18. However, K is now defined to include the deep ground water component and is called K' .

$$P_t = \frac{K'P_nR+P_m}{1+K'R} \qquad (5\text{-}27)$$

where

$$K' = \frac{1-f_{en}-f_{dn}}{1-f_{em}-f_{dm}} \quad . \qquad (5\text{-}28)$$

The parameters R , P_n , and P_m remain as previously defined.

CHAPTER VI

MODEL TESTING AND APPLICATION

The validity of the water quality model developed in the preceeding chapter is tested using data collected at the Edna Mine. The average salt concentrations in drainage from the mine watersheds predicted by the model are compared with those actually measured in the field. Two simplified versions of the model are presented and compared with the original model. Finally an example is given demonstrating possible applications of the model in predicting the water quality of drainage from surface mines.

Testing the Water Quality Model

The water quality model represented by equation 5-18 predicts that the average concentration of runoff from a mine watershed will depend upon precipitation, evapotranspiration from natural and mined land, the fraction of the watershed mined, and average concentrations of surface and subsurface water from the natural and mined portions. If these parameters, except for the fraction of the watershed mined, do not vary from one watershed to another, then a plot of R versus the average concentration of runoff, P_t, for all watersheds on the mine will fall along a single curve. Such a plot is shown in Figure 6-1. The scatter in the data points plotted is probably the result of assuming that the parameters in the model do not vary over the entire area of the mine. Differences in vegetation, slope aspect, geology, soils, and a number of other factors will cause the parameters used in the model to change from one watershed to another. These parameters can also vary from one year to the next on the same watershed. The points labeled C9 + C10 in Figure 6-1 were found by combining the C9 and C10 watersheds and treating them

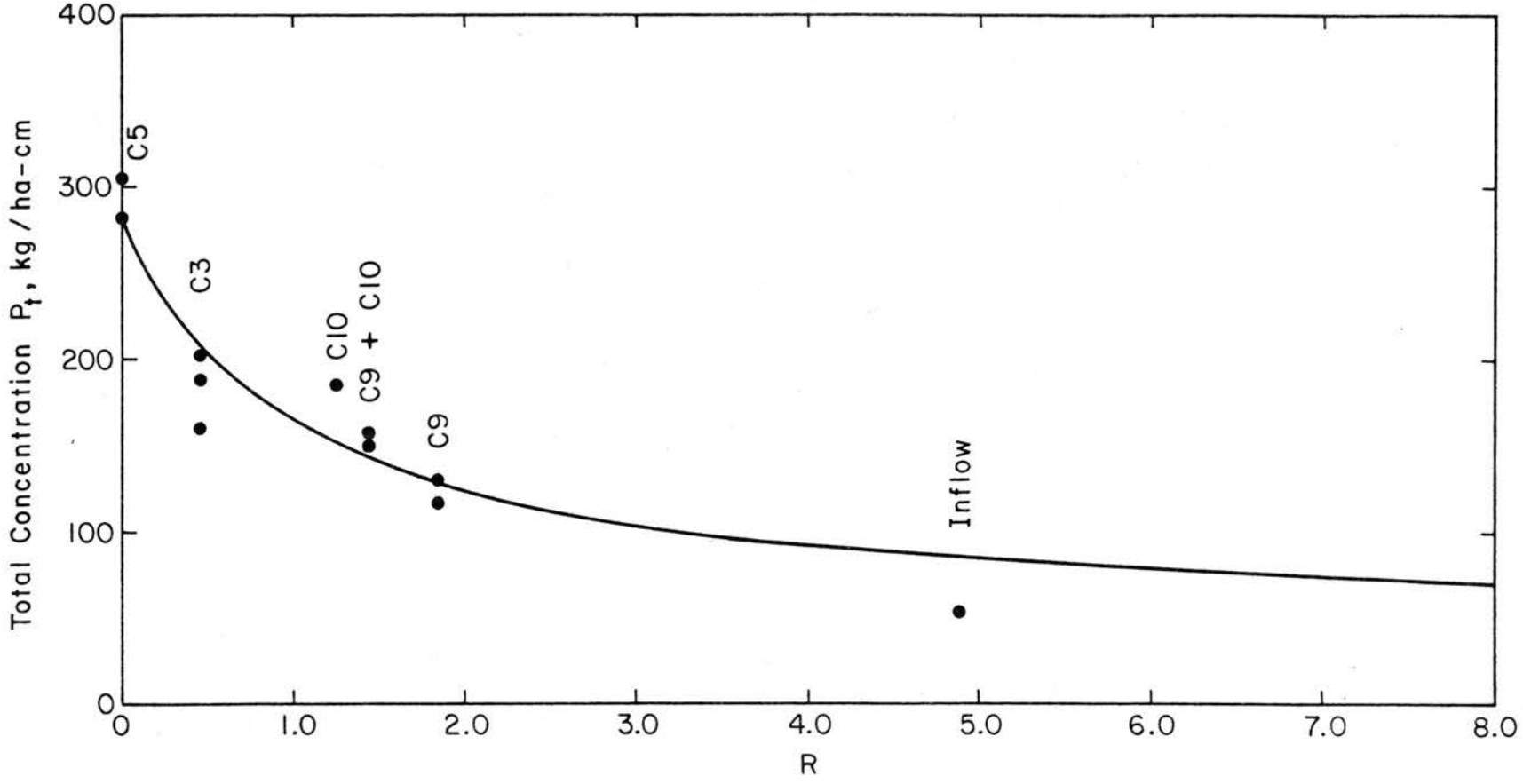

Figure 6-1. Plot of R versus P_t with best fit curve found for K = 1.04, f_s = 0.06.

as one watershed. As explained in Chapter IV, some water flowed from C10 into C9 thus having an effect upon the average concentration of both watersheds.

With the data plotted in Figure 6-1, it is possible to fit a curve through the points by using a least squares regression. In order to reduce the number of unknown parameters and thus simplify the regression procedure, it is assumed that the fraction of runoff occurring as overland flow is the same from both natural and mined land, that is, $f_{sn}=f_{sm}=f_s$. With this assumption, values of K and f_s can be found which achieve a best fit to the data points. This is accomplished by a trial and error procedure which minimizes the sum of the squares of the differences between measured values of P_t and values calculated from equation 5-18. That is,

$$\Sigma(P_t - \frac{KP_nR-P_m}{1+KR})^2 = \text{minimum} \quad . \tag{6-1}$$

A best fit is found for values of $K=1.04$ and $f_s=0.06$. These values indicate that evapotranspiration is approximately the same from mined and natural land and very little runoff occurs as overland flow.

Data points from Stations C3, C5, C9, and C10 are used in the regression. Inflow and the points marked C9 + C10 are not used. The total watershed contributing to inflow between Stations C2 and C6 has an area of over 3500 ha and ranges in elevation from approximately 2100 m to 2800 m . The Edna Mine watersheds are each less than 500 ha in area and range in elevation from 2100 m to 2500 m . Thus, a difference in precipitation, vegetation, evapotranspiration, etc. can be expected between the total inflow watershed and the Edna Mine watersheds. Watershed parameters used in the model to describe the mine watersheds

can be expected to vary significantly over the entire inflow watershed between Stations C2 and C6. The basic assumptions of dynamic equilibrium and a constant total dissolved solids concentration for individual flow components may also be invalid over the large and varied inflow watershed. The point representing the inflow watershed can not be expected to fall along the same curve as defined by the mine watersheds, therefore.

The curve in Figure 6-1 intersects the vertical axis at a value of P_t equal to 286 kg/ha-cm which is the average concentration of drainage from mined land. It approaches asymptotically a value of P_t equal to 44 kg/ha-cm which is the average concentration of drainage from natural land. This can be considered the concentration of combined overland flow and subsurface runoff before mining occurred.

Table 6-1 shows the values of average concentration measured in the field and calculated by the model. Agreement between observed and calculated values is fairly good except for the entire inflow watershed which is calculated to be about 38 percent higher than is observed. The C10 watershed is about 20 percent higher than the model predicts prehaps due to the loss of high quality water to the C9 watershed as previously explained.

Actual values of evapotranspiration are not used to find K directly. It appears from the value found for K that evapotranspiration is approximately the same for natural and mined land. There is a need to develop criteria by which K can be estimated although it is beyond the scope of this study to do so. Numerous methods have been used to estimate evapotranspiration but seldom have they been applied to areas with the vegetation, soils, and climate such as is found at the Edna Mine. Wymore (1974a) finds the potential evapotranspiration in a similar area by using

Table 6-1

Observed and Calculated Average Salt Concentrations

Station	Year	R	Observed P_t (kg/ha-cm)	Calculated P_t (kg/ha-cm)	% Difference
C3	1974	0.47	203	206	+ 1.5
C5	1974	0.00	283*	286	+ 1.0
C3	1975	0.47	189	206	+ 8.3
C5	1975	0.00	283*	286	+ 1.0
C9	1975	1.86	129	126	- 2.3
C10	1975	1.27	186	148	-20.4
C9+C10	1975	1.44	158	141	-10.8
Inflow	1975	4.88	52	84	+38.1
C3	1976	0.47	161	206	+21.8
C5	1976	0.00	308*	286	- 7.1
C9	1976	1.86	119	126	+ 5.6
C10	1976	1.27	185	148	-20.0
C9+C10	1976	1.44	152	141	- 7.2

*P_t calculated only from TDS data.

solar radiation data and adjusting for elevation zone, slope aspect, temperature, and season. He then applies plant coefficients and measured precipitation to estimate actual evapotranspiration on a monthly basis. The method has been successfully applied in determining an annual water balance for the Piceance and Yellow Creek watersheds in northwestern Colorado (Wymore, 1974b).

The fraction of mine drainage coming from overland flow was also not directly measured. The parameter f_s depends upon such factors as infiltration capacity, plant cover, rainfall, snowmelt, and the efficiency of the surface drainage pattern. A detailed study of these and other factors may provide the necessary criteria for selecting a value of f_s but this is again beyond the scope of this study.

Several curves of R versus P_t are shown in Figure 6-2 for various values of K and f_s. The concentrations of surface and subsurface water found at the Edna Mine are used to calculate these curves. As expected, increasing the fraction of overland flow while holding K constant decreases the concentration of the total runoff. The decrease occurs because smaller volumes of water infiltrate with increased overland flow. This results in a greater proportion of high quality overland flow and a smaller proportion of low quality subsurface flow in the combined surface and subsurface runoff from the watershed. With a constant fraction of overland flow the total concentration will also decrease if the volume of water lost through evapotranspiration is increased. This again allows less water to infiltrate into the ground and, therefore, decreases the dissolved solids concentration of combined surface and subsurface runoff.

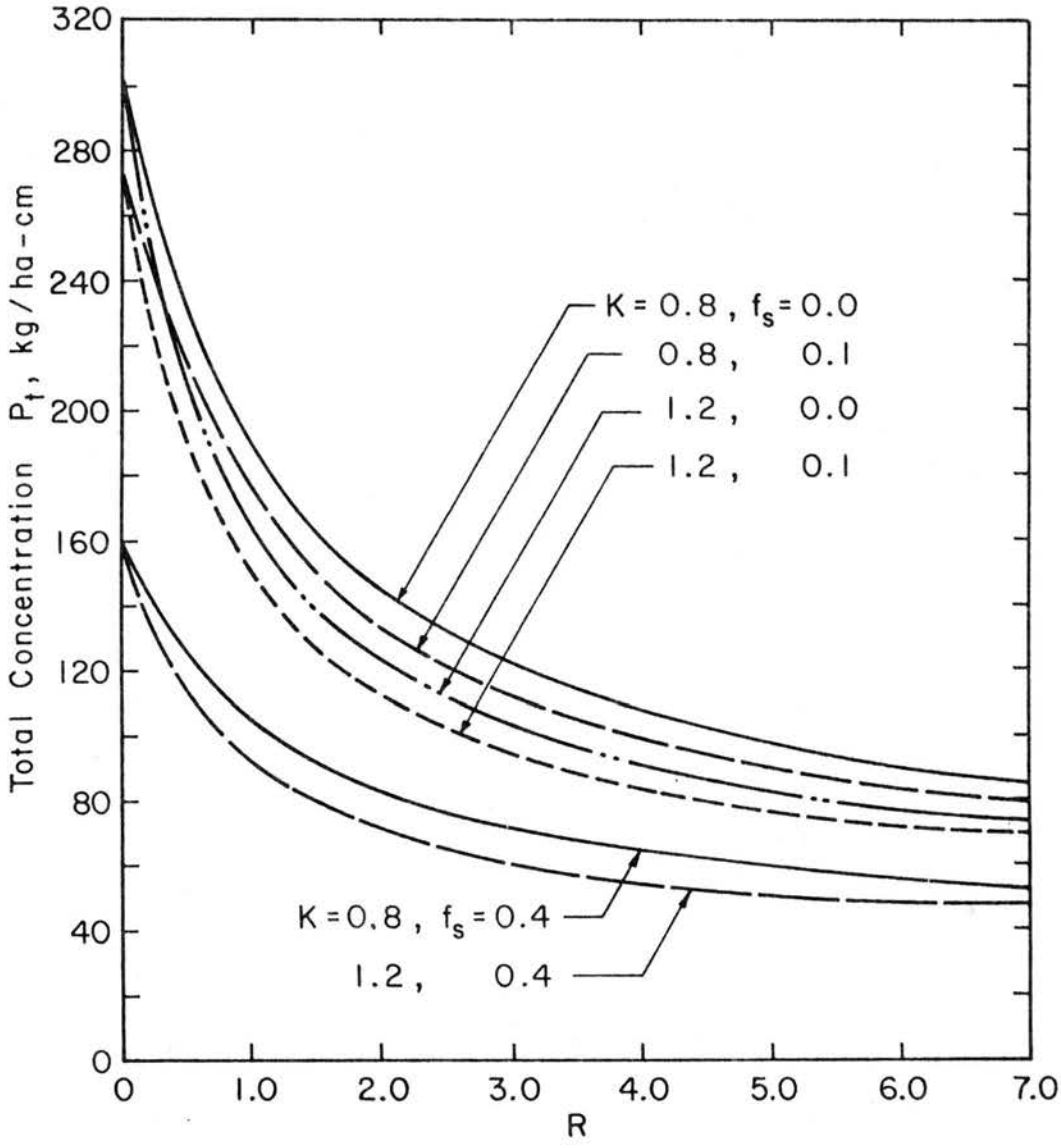

Figure 6-2. Plot of R versus P_t for various values of K and f_s .

Simplified Versions

The water quality model can be further simplified if certain assumptions are made. At the Edna Mine the errors introduced by these simplifications are evidently much smaller than existing differences between the watershed parameters, thus very little accuracy is lost by using the simple versions.

Version 1

If the evapotranspiration is assumed to be equivalent on mined and natural land, then the parameter K will equal unity. This condition is closely approximated on the Edna Mine watersheds where K is found to be equal to 1.04. With this assumption the combination of water and mass balances represented by equation 5-13 can be written as

$$P_t = F_m(P_m - P_n) + P_n \quad . \tag{6-2}$$

Equation 6-2 states that the average salt concentration varies linearly with the fraction of watershed that is mined. Substituting equations 5-22 and 5-23 for P_m and P_n yields

$$P_t = F_m[f_{sm}P_{sm} + (1-f_{sm})P_{gm}] + (1-F_m)[f_{sn}P_{sn} + (1-f_{sn})P_{gn}] \quad . \tag{6-3}$$

Assuming that $f_{sm}=f_{sn}=f_s$ and $P_{sm}=P_{sn}=P_s$, equation 6-3 can be written as

$$\frac{P_t-P_{gn}}{P_{gm}-P_{gn}} = F_m(1-f_s) - f_s\left(\frac{P_{gn}-P_s}{P_{gm}-P_{gn}}\right) \quad . \tag{6-4}$$

Equation 6-4 is plotted in Figure 6-3 for values of $f_s=0.00$ and $f_s=0.05$. There is considerable scatter of the data points as explained in the original version. Inflow and Station C3 again plot lower than predicted. If evapotranspiration can be considered the same on natural

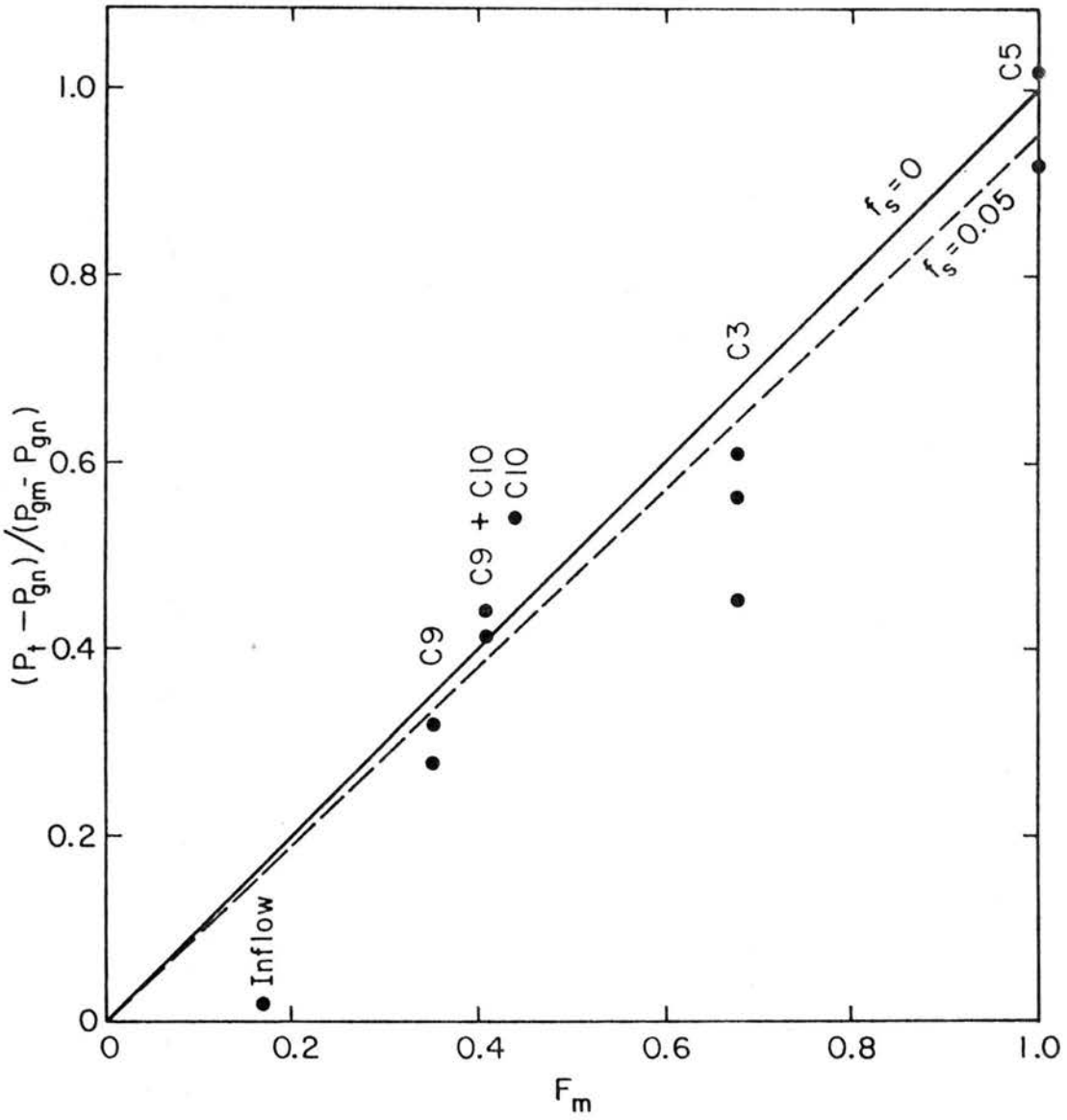

Figure 6-3. Plot of model simplified when K = 1.00 .

and mined portions of the watershed, equation 6-4 can be used as a special case of the general model represented by equation 5-18.

Version 2

One additional case is considered in which the fraction of overland flow, f_s , equals zero. Equation 6-4 now becomes

$$P_t = F_m(P_{gm}-P_{gn}) + P_{gn} \quad . \qquad (6\text{-}5)$$

A plot of F_m versus P_t should now yield a straight line with slope equal to $(P_{gm}-P_{gn})$ and intercept equal to P_{gn} . A linear regression was made using data from Stations C5, C9, and C10 to yield the equation

$$P_t = 232\ F_m + 62 \qquad (6\text{-}6)$$

with a coefficient of determination, $r^2=0.94$. Station C3 was left out of this first regression because concentrations of total dissolved solids measured there are consistantly lower than expected. As previously explained, this could be due to the older age of the spoils or an error in determining the area mined. Equation 6-6 is plotted as line A in Figure 6-4. The slope, $(P_{gm}-P_{gn})$, and intercept, P_{gn} , in equation 6-5 can be set equal to the regression coefficients in equation 6-6. Values of $P_{gm}=294$ kg/ha-cm and $P_{gn}=62$ kg/ha-cm are found for line A as compared to values measured in the field of $P_{gm}=303$ kg/ha-cm and $P_{gn}=46$ kg/ha-cm .

Line B in Figure 6-4 is found in the same manner using all data points with the exception of inflow and the combined C9 + C10 . Regression yields the equation

$$P_t = 229\ F_m + 53 \qquad (6\text{-}7)$$

with $r^2=0.86$. For equation 6-7, $P_{gm}=282$ kg/ha-cm and $P_{gn}=53$ kg/ha-cm .

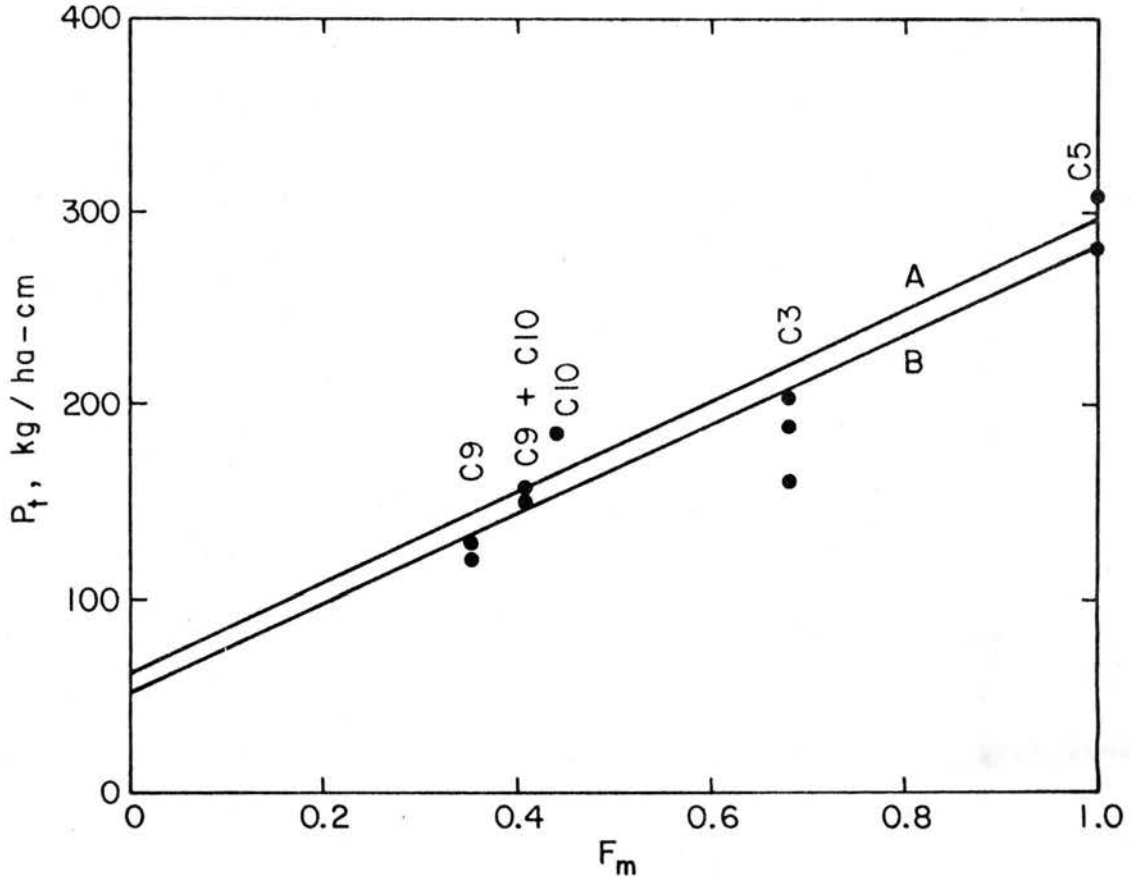

Figure 6-4. Plot of model simplified when K = 1.00 and f_s = 0.00 .

This simple version can be used in several ways for situations where overland flow is very small. If the concentrations of subsurface water from the mined and natural land are known or can be estimated from water samples or soil samples, then the average concentration of runoff from a mined watershed can be predicted. If average concentrations of runoff have been measured on several mine watersheds, then a regression can be made and the concentrations of subsurface water on the natural and mined land estimated.

Comparison of Model Versions

The two simple versions of the more general water quality model are special cases of equation 5-18. They can be used in areas where the necessary assumptions can be made without introducing large errors. Table 6-2 gives a comparison of average concentrations found using equation 5-18, equation 6-4 and equation 6-5 along with the percent difference between each calculated concentration and that actually observed. The average error of each version, disregarding the values for the total inflow between Stations C2 and C6 and C9 + C10 , is also shown and is about 9 percent for all three versions of the model. This indicates that on the Edna Mine the simplifying assumptions can be applied without introducing much error in the calculated average concentrations.

High potential evapotranspiration, low precipitation, and poor surface drainage are common conditions occurring on western surface mines and, thus, the two simple versions of the model may be applicable. Much more data from other mines is needed before the general applicability of any version of the model can be stated. If methods allowing the more precise determination of evapotranspiration and overland flow are found then the general version of the water quality model should predict

Table 6-2

Comparison of Salt Concentrations Predicted by Various Versions of the Model

Station	Year	Observed P_t kg/ha-cm	Pred. P_t Eq.5-18* kg/ha-cm	Error %	Pred. P_t Eq.6-4** kg/ha-cm	Error %	Pred. P_t Eq.6-5 kg/ha-cm	Error %
C3	1974	203	206	+ 1.5	210	+ 3.3	209	+ 2.9
C5	1974	283	286	+ 1.0	289	+ 2.1	282	- 0.4
C3	1975	189	206	+ 8.3	210	+10.0	209	+ 9.6
C5	1975	283	286	+ 1.0	289	+ 2.1	282	- 0.4
C9	1975	129	126	- 2.3	130	+ 0.8	133	+ 3.0
C10	1975	186	148	-20.4	152	-18.3	154	-17.2
C3	1976	161	206	+21.8	210	+23.3	209	+23.0
C5	1976	308	286	- 7.1	289	- 6.2	282	- 8.4
C9	1976	119	126	+ 5.6	130	+ 8.5	133	+10.5
C10	1976	185	148	-20.0	152	-17.8	154	-16.8
		Average Error		8.9		9.2		9.2
Inflow	1975	52	84	+38.1	86	+39.5	92	+43.5
C9+C10	1975	158	141	-10.8	145	- 8.2	147	-11.4
C9+C10	1976	152	141	- 7.2	145	- 4.6	147	- 7.9

*$K = 1.04$, $f_s = 0.06$

**$f_s = 0.05$

average dissolved solids concentrations in mine drainage with the greatest accuracy.

Possible Application of the Model

The water quality model derived in the preceding chapter and tested in this chapter may prove to be of practical use to those persons and agencies who must make decisions concerning mining permits, environmental impact, and reclamation. The model does not require particularly expensive data gathering and can be applied with ease and speed once appropriate data are available. More study is needed before parameters used in the model can be routinely selected for a specific area. This is particularly true in selecting values for K, f_{sm}, and f_{sn}.

An example is presented below to illustrate how the model can be used to predict the impact of surface mining on water quality. Several parameters are varied to correspond to different physical conditions existing on a hypothetical surface mine. The five cases considered are; the natural case before mining activity, a case with conditions similar to the Edna Mine ($K \simeq 1.00$, $f_s \simeq 0.05$), a case with the proportion of total runoff occurring as overland flow on the mined land increased, a case with evapotranspiration on the mined land increased, and a combination of increased overland flow and evapotranspiration on the mined land.

Example Calculation

A hypothetical surface mine comprising 800 hectares of disturbed land surface in a total watershed of 1000 hectares is considered. The average concentrations of surface water and subsurface water from natural and mined areas have been determined from water samples or spoil samples as explained previously. For the purpose of this example concentrations of these flow components are assumed equal to those found at the Edna

Mine. The concentrations are P_s=150 mg/ℓ , P_{gn}=460 mg/ℓ , and P_{gm}=3030 mg/ℓ . It is assumed that hydrologic conditions are similar to those found at the Edna Mine and the water quality model can be applied without modifications. Precipitation is 50 cm per year and evapotranspiration on natural land is 30 cm per year, again approximately the values at the Edna Mine.

Four cases are considered in which evapotranspiration or overland flow from the mined land is varied. Table 6-3 contains the model parameters and results. It is assumed that mine drainage enters an adjacent stream which has an annual average discharge volume of 2800 ha-m per year measured just downstream of the mine. The total dissolved solids concentration of the adjacent stream just upstream of the mine is 120 mg/ℓ.

The natural watershed before mining will have an average runoff concentration which reflects a combination of overland flow and subsurface water as indicated by equation 5-23. This is the average concentration of combined surface and subsurface runoff from the watershed before mining. In this example the average concentration from the mine watershed is 445 mg/ℓ with 200 ha-m of runoff volume. The watershed before mining contributes 8.9×10^5 kg of salts a year to the adjacent stream which results in a 143 mg/ℓ concentration of salts in the adjacent stream immediately below the mine.

Case 1 is meant to reflect the conditions existing on graded spoils with no further compaction and little vegetation. This is the condition occurring over most of the Edna Mine. The evapotranspiration on mined and natural land is assumed to be equivalent and is 30 cm per year. This results in a K parameter equal to 1.00 , close to the value of 1.04 found at the Edna Mine. The decrease in evapotranspiration which

Table 6-3

Example Application of the Model*

Parameters on Annual Basis	Natural	Case 1	Case 2	Case 3	Case 4
Precipitation (cm)	50	50	50	50	50
E-T, natural land (cm)	30	30	30	30	30
E-T, mined land (cm)	-	30	30	35	35
K	-	1.00	1.00	1.33	1.33
R	-	0.25	0.25	0.25	0.25
f_{sn}	0.05	0.05	0.05	0.05	0.05
f_{sm}	-	0.05	0.30	0.05	0.30
P_t (mg/ℓ	445	2400	1740	2280	1660
Runoff (ha-m)	200	200	200	160	160
Salt load (kgx10^{-3})	890	4800	3480	3640	2660
Salt increase	0%	540%	390%	410%	300%
TDS in adjacent stream below mine drainage (mg/ℓ)	143	283	236	247	211

*Total Area = 1000 ha
Mined Area = 800 ha
Average yearly discharge volume in adjacent stream measured just downstream of mine = 2800 ha-m/yr
Average yearly TDS concentration in adjacent stream above mine drainage = 120 mg/ℓ
P_s = 150 mg/ℓ
P_{gn} = 460 mg/ℓ
P_{gm} = 3030 mg/ℓ

logically should be caused by the destruction of vegetation on the mined land may be compensated for by an increase in evaporation from ponded water so that the parameter K remains equal to unity. The fraction of runoff from overland flow is assumed for this case to be 0.05 on both natural and mined portions of the watershed.

The model predicts an average runoff concentration of 2400 mg/ℓ resulting in 4.8×10^6 kg of salts discharged per year. This is an increase of 540 percent over natural conditions and represents the worst water quality of the cases considered. Note that the model predicts that, if evapotranspiration decreases on the mined land without an accompanying increase in overland flow, the concentration of total runoff will be even greater due to greater infiltration volumes.

The salt concentration in the adjacent stream can be calculated by a simple mixing equation,

$$V_t P_t = V_{mw} P_{mw} + V_{nw} P_{nw} \quad , \tag{6-8}$$

where V refers to discharge volume, P refers to TDS concentration, and the subscripts t , mw , and nw refer to the total watershed including the mine, the mine watershed, and the watershed above the mine respectively. The concentration in the stream is 283 mg/ℓ which is 140 mg/ℓ above the natural concentration.

In the second case considered the fraction of overland flow is increased from 0.05 to 0.30 on mined land with all other parameters remaining the same. An increase in the amount of overland flow may possibly be achieved by careful grading of the spoils to restore adequate surface drainage patterns and avoid ponding, by compacting the surface of the spoils to reduce infiltration, or by some other method.

The decrease in the volume of water infiltrating into the spoils results in a reduction of the mine drainage concentration to 1740 mg/ℓ . This corresponds to 3.5×10^6 kg of salts discharged per year which is 390 percent above natural levels. The concentration in the adjacent stream below the mine is 236 mg/ℓ for a reduction of 47 mg/ℓ from Case 1.

The third case considered demonstrates the effect of increasing evapotranspiration on mined land. Annual evapotranspiration is increased from 30 cm to 35 cm changing the parameter K from 1.00 to 1.33 . Such an increase may be the result of extensive revegetation or increased compaction allowing more ponded water on the spoils to evaporate. All other parameters in this case are the same as in Case 1.

The reduction in average total dissolved solids concentration over Case 1 is small, from 2400 mg/ℓ to 2280 mg/ℓ . However, the net outflow of salts is decreased substantially due to lower volumes of runoff. The total quantity of salts discharged is 3.6×10^6 kg per year for a 440 percent increase above natural levels, slightly more than Case 2. The concentration in the adjacent stream is 247 mg/ℓ , still a substantial reduction from Case 1. There can also be an additional detriment caused by the reduction in runoff volume from 200 ha-m to 160 ha-m which should be evaluated.

The final case considered represents a combination of Cases 2 and 3. Overland flow and evapotranspiration are both increased on mined land. This results in an average runoff concentration of 1660 mg/ℓ for a net outflow of 2.7×10^6 kg of salts per year. The increase in concentration is 300 percent above natural levels but a 45 percent reduction over

Case 1. The concentration in the adjacent stream is 211 mg/ℓ . As in Case 3 the effect of decreased volumes of runoff must be considered also.

This example is not supposed to reflect actual reductions in salt concentrations as a result of any particular method of reclamation. Much more study is needed before the model parameters can be chosen to correspond to a given reclamation method. The purpose in the example is to demonstrate how the model can be used concerning reclamation, mining permits, environmental impact, etc. if the parameters used in the model can be determined.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The study undertaken at the Edna Mine provides the detailed observations of climatic, geologic, and hydrologic conditions needed in ascertaining the relationship of these factors to the water quality hydrology. Measurement of discharge and total dissolved solids content of water at selected monitoring sites allows the computation of total salt load in runoff from the mine watersheds and the net inflow of salts to Trout Creek between Station C2 above the mine drainage and Station C6 near the lower boundary of the mine drainage.

A single-equation model is developed on the basis of water and mass balances for the mine watersheds which predicts the average annual salt concentration of total runoff from the watersheds. This average concentration is related by the model to parameters describing the average salt concentrations of surface and subsurface flow components, the area mined, precipitation, evapotranspiration, and overland flow.

The model is developed and tested specifically on the basis of conditions existing on the Edna Mine. Many other surface mines or potential surface mines in the western United States can be expected to display similar conditions. The present model or modified versions may, therefore, be applicable in these areas.

The need for a method to predict water quality degradation due to dissolved salts is especially apparent when the economic detriments due to increased salts are considered. Rising salt concentrations are of special concern to water users in the Lower Colorado River Basin.

Many specific conclusions can be stated as a result of this study. These relate to the observed water quality hydrology on the Edna Mine

and the use of the water quality model developed and tested in this report. These conclusions are:

1. There is significant degradation of water quality in Trout Creek along its reach adjacent to the Edna Mine. The annual salt load increases two to three times along this length of Trout Creek.
2. About 70 to 80 percent of the additional inflow of salts into Trout Creek near the Edna Mine occurs during April, May, and June. These months correspond to the period of heavy spring runoff due to snowmelt on the mine.
3. Most average ion concentrations in water draining from the mine are generally below drinking water standards. Total dissolved solids regularly exceed the 500 mg/ℓ standard by several times and, therefore, constitute the major source of water degradation. Sulfates are generally above standards in mine drainage. Average manganese concentrations exceed standards only on the C3 watershed which contains the oldest mine spoils.
4. Average water quality in Trout Creek is below drinking water standards. In March and April, when discharge in Trout Creek is low and discharge from the mine area is proportionately higher than during the rest of the year, total dissolved solids in Trout Creek downstream from the mine did exceed the 500 mg/ℓ standard.
5. The concentrations of dissolved salts in the various flow components of mine drainage are dependent upon the potential

availability of salts within the geologic material. Mining increases the availability by exposing unleached rock material containing large quantities of potential solutes and by increasing the depth of water percolation from several meters on undisturbed land to over fifteen meters on mined land.

6. Overland flow on both natural and mined land was low in dissolved salts due to rapid leaching of the top layer of natural soil and spoils. An average of 150 mg/ℓ was found for the overland flow component of total runoff. No significant difference was found between concentrations of overland flow on the spoils and undisturbed land.
7. The concentration of salts in subsurface water varied greatly between natrual and mined portions of the watersheds. Subsurface water on natural land averaged about 460 mg/ℓ while that on mined land averaged about 3025 mg/ℓ .
8. The actual salt concentrations of subsurface water on both natural and mined land can be approximated by saturated paste analysis of soil and spoil samples. Eleven spoil samples taken in 1973 averaged 3130 mg/ℓ total dissolved solids. Three spoil samples taken in 1976 averaged 2820 mg/ℓ . Both of these values are close to the average concentration of 3030 mg/ℓ found from subsurface water samples. Eleven soil samples from undisturbed land averaged about 380 mg/ℓ which is somewhat lower than a value of 460 mg/ℓ estimated from water samples on undisturbed land.
9. Leaching tests (conducted without considering the effect of weathering) indicate that about 6.8 m^3 of water are needed

to reduce the electrical conductivity of one cubic meter of spoils by 95 percent. This reduction yields 2.4 kg of salts per cubic meter of spoils. A reduction in conductivity of 45 percent will result if 2 m^3 of water are passed through one cubic meter of spoils. Other leaching tests indicate that weathering can replace solutes within the spoils. Thus, the above numbers are probably low.

10. There will be no significant reduction of salts in the spoils for a long period of time because annual leaching volumes are small. With 20 cm of annual leaching volume it is estimated that 100 years is needed to achieve a 45 percent reduction in salts if the spoils are 20 m in thickness. This estimate again does not allow for any replacement of solutes by weathering.
11. Salt production from the mined land is estimated to be 303 kg of salts per hectare for each centimeter of percolating water. Salt production on undisturbed land (pre-mining conditions) is estimated to be 46 kg/ha-cm . If 20 cm of water precolates into the spoils per year, salt production is estimated to be 6060 kg/ha on mined land and 920 kg/ha on undisturbed land for an increase due to mining of 5140 kg/ha.
12. Data indicate that the mine watersheds can be considered to be in an approximate dynamic equilibrium over a year's time. Total water inflow will equal total outflow plus any losses within the watershed.
13. The water quality model is independent of the actual volumes of the various flow components. The model parameters K , f_{sn} ,

and f_{sm} are defined as ratios of water volumes and can remain constant even though actual volumes of water may vary from year to year.

14. The model estimates the average annual concentration of combined runoff from overland and subsurface flow from the Edna Mine watersheds with an average error of prediction of about 9 percent.

15. Several simplifications of the model are possible if evapotranspiration is equivalent on mined and natural land (K=1.00) and if overland flow is very small ($f_s \simeq 0.00$). These simplifications are valid on the Edna Mine and do not introduce any significant error into the predicted values of average concentration.

16. Specific data needed to apply the water quality model include estimates of precipitation, evapotranspiration, and overland flow. Also the average annual total dissolved solids concentrations in the flow components of overland and subsurface flow from mined and undisturbed land and the fraction of the watershed mined are needed.

The water quality model can be useful to those people who must make important decisions concerning mining permits, environmental impact, and reclamation of surface coal mine land. The model predicts water quality with a minimum of detailed data making it attractive when little information or money is available for some other more complex analysis.

Improvement in the predictive capabilities of the model developed in this study will come from both an increased understanding of the processes governing the model parameters and improved data gathering

networks on coal-bearing lands. The processes of overland flow, evapotranspiration, and the solution of salts from spoils must be clearly understood in order that estimates of these parameters as used in the model can be made with a minimum of data required. The natural process of salt pickup in waters on undisturbed watersheds must also be closely examined if the impact of mining on water quality is to be understood. Networks of stations gathering the specific type of data required to test the validity of the model consitute an important step.

General validation of the model requires comprehensive data gathering, testing, and analysis on a number of mine watersheds. Initial testing with data from the Edna Mine demonstrates the feasibility of the approach taken to predict water quality. If further testing proves equally successful, the basic model presented can be an important tool in the planning and management of water resources in the western coal fields.

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Appendix A

Water Quality Data - Monthly Samples

Table A-1. Water Analysis for July 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	22	0	98	130	8.1	190		120		<0.5	41	<1	<0.09	<0.08			0.93	9.2	<0.01	2.8	<0.1	9	<0.01
C2	22	0	100	140	8.3	190		140		<0.5	43	<1	<0.09	<0.08			0.93	9.2	<0.01	2.7	<0.1	8	<0.01
C3	25	0	83	2100	8.0	2280		2300		<0.5	360	4	<0.09	<0.08			2.7	130	0.069	18	<0.1	1300	<0.01
C4	22	0	110	180	8.2	275		210		<0.5	50	1	<0.09	<0.08			1.3	13	0.015	4.0	<0.1	53	<0.01
C5	22	0	200	2800	8.2	3600		3300		<0.5	350	5	<0.09	<0.08			15	290	0.018	120	<0.1	180	<0.01
C6	21	0	120	190	8.2	227		200		<0.5	53	1	<0.09	<0.08			1.4	15	0.018	5.7	<0.1	14	<0.01
C7	10	0	360	2600	7.6	4900		4000		<0.5	360	8	<0.09	<0.08			14	210	0.019	460	<0.1	1200	<0.01
C8	10	0	120	200	8.0	440		310		<0.5	60	1	<0.09	<0.08			1.5	16	0.014	6.3	<0.1	11	<0.01

Table A-2. Water Analysis for August 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	18	0	98	130	8.2	202		110		<0.5	38	<1	<0.09	<0.1			1.1	9.4	0.016	2.7	<0.14		<0.01
C2	17	0	100	140	8.1	204		120		<0.5	35	<1	<0.09	<0.1			1.1	9.5	<0.01	2.8	<0.14		<0.01
C3	21	0	83	2100	8.0	2450		330		<0.5	400	4.0	<0.09	<0.1			3.0	160	0.072	19	<0.14		<0.01
C4	18	0	110	180	8.2	285		170		<0.5	48	<1	<0.09	<0.1			1.2	15	0.010	3.6	<0.14		<0.01
C5	19	0	200	2900	8.2	3650		3330		<0.5	340	5.0	<0.09	<0.1			16	300	0.013	44	<0.14		<0.01
C6	14	0	110	190	8.2	301		190		<0.5	52	<1	<0.09	<0.1			1.3	14	0.010	4.6	<0.14		<0.01
C7	18	0	360	2500	7.6	4800		4000		<0.5	310	9.0	<0.09	<0.1			14	200	0.016	490	<0.14		<0.01
C8	18	0	120	190	8.2	326		190		<0.5	52	<1	<0.09	<0.1			1.3	16	0.010	5.4	<0.14		<0.01

Table A-3. Water Analysis for September 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	14	0	100	150	8.2	220		150		<0.2	36	<1	<0.02	<0.1			1.2	8.8	0.013	3.4	<0.14		0.016
C2	14	0	110	150	8.1	224		145*		<0.2	38	<1	<0.02	<0.1			1.2	10	<0.01	3.8	<0.14		<0.01
C3	15	0	98	2400	8.1	2650		2210		<0.2	410	4.5	<0.02	<0.1			3.4	170	0.059	22	<0.14		<0.01
C4	10	0	160	430	8.2	635		430		<0.2	110	1.5	<0.02	<0.1			2.8	44	0.017	14	<0.14		<0.01
C5	11	0	220	2200	8.1	3700		3490		<0.2	320	5.5	<0.02	<0.1			15	280	0.018	160	<0.14		<0.01
C6	8	0	140	310	8.1	490		310		<0.2	94	<1	<0.02	<0.1			2.4	24	0.014	13	<0.14		<0.01
C7	8	0	370	1600	7.8	4700		3850		<0.2	290	8.0	<0.02	<0.1			14	180	0.015	580	<0.14		<0.01
C8	8	0	140	320	8.1	525		320		<0.2	110	1.5	<0.02	0.12			2.5	30	0.031	16	<0.14		<0.01

*From correlation of EC vs. TDS.

Table A-4. Water Analysis for October 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	11	0	110		8.0	214		170		<0.2	36	<1	<0.02	<0.1			1.1	11	0.03	3.5	<0.14		0.01
C2	11	0	110		8.0	223		170		<0.2	35	<1	<0.02	<0.1			1.1	11	0.013	3.7	<0.14		<0.01
C3	12	0	100		8.0	2900		2310		<0.2	370	4	<0.02	<0.1			3.5	190	0.047		<0.14		<0.01
C4	12	0	120		8.0	345		240		<0.2	52	1	<0.02	<0.1			1.5	18	0.020	5.6	<0.14		<0.01
C5	12	0	190		8.1	3950		3220		<0.2	310	6	<0.02	<0.1			16	280	0.013	170	<0.14		0.01
C6	12	0	130		8.1	395		270		<0.2	58	1	<0.02	<0.1			1.7	20	0.024	8.7	<0.14		0.025
C7	8	0	360		7.5	4900		4260		<0.2	260	9	<0.02	<0.1			13	170	0.013	510	<0.14		0.01
C8	11	0	130		8.3	535		300		<0.2	60	1	<0.02	<0.1			1.8	24	0.025	14	<0.14		<0.01

Table A-5. Water Analysis for November 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	1	0	120	240	8.5	249		170		<0.2	39	<1	<0.011	<0.08			0.96	13	0.028	3.8	<0.10		<0.01
C2	1	0	110	240	8.3	261		130		<0.2	35	<1	<0.011	<0.08			0.96	13	0.012	3.8	<0.10		<0.020
C3	5	0	<10	3700	8.4	2780		2460		<0.2	380	4	<0.011	<0.08			3.6	160	0.064	28	<0.10		<0.01
C4	4	0	130	430	8.5	458		290		<0.2	67	1	<0.011	<0.08			1.6	26	0.028	7.0	<0.10		<0.01
C5	4	0	140	4800	8.4	3870		3200		<0.2	270	6	0.018	<0.08			14	290	0.018	130	<0.10		<0.01
C6	4	0	140	550	8.6	558		370		<0.2	75	1	<0.011	<0.08			1.7	33	0.032	10	<0.10		<0.01
C7	4	0	360	3800	8.3	4840		3720		<0.2	280	8	0.019	<0.08			13	170	0.014	520	<0.10		0.012
C8	3	0	130	500	8.5	567		360		<0.2	73	2	<0.011	<0.08			1.6	28	0.029	14	<0.10		<0.01

Table A-6. Water Analysis for December 1974.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0	0	100	130	7.9	226		140		<0.2	32	<1		<0.08			0.88	11	0.016	3.4	<0.1		<0.01
C2	0	0	100	110	7.7	246		140		<0.2	33	<1		<0.08			0.96	12	<0.01	3.8	<0.1		<0.01
C3	2	0	130	1900	8.1	2600		2530		<0.2	410	-		<0.08			3.6	180	0.10	29	<0.1		0.01
C4	0	0	110	140	8.0	302		180		<0.2	46	<1		<0.08			1.1	15	0.015	4.7	<0.1		<0.01
C5	2	0	200	2800	8.1	4220		4160		<0.2	340	6		<0.08			17	320	0.024	250	<0.1		0.013
C6	0	0	120	150	8.3	323		190		<0.2	48	1		<0.08			1.1	17	0.017	5.8	<0.1		<0.01
C7	4	0	370	1900	8.0	4400		3800		<0.2	300	8		<0.08			13	180	0.020	530	<0.1		0.01
C8	0	0	120	150	8.2	338				<0.2	52	1		<0.08			1.2	17	0.018	7.5	<0.1		<0.01

Table A-7. Water Analysis for January 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0	0	100	94	8.1	162	<2	150	150	<0.2	30	<1	<0.001	<0.1	0.47	0.47	0.69	10	0.015	3.4	<0.1	3	<0.01
C2	0	0	99	96	8.1	178	<2	140	140	<0.2	33	<1	<0.001	<0.1	0.18	0.18	0.74	10	<0.01	3.5	<0.1	22	<0.01
C3	0	0	140	1700	7.8	2410	<2	2280	2280	<0.2	370	4	<0.001	<0.1	0.30	0.30	3.1	150	0.25	23	<0.1	1550	0.019
C4	0	0	100	130	8.0	251	<2	160	160	<0.2	40	<1	<0.001	<0.1	0.20	0.20	0.86	15	0.026	4.7	<0.1	27	0.01
C5	0	0	190	2280	8.0	3250	119	3300	3420	<0.2	310	4	<0.001	<0.1	2.6	2.6	14	270	0.030	140	<0.1	2300	0.011
C6	0	0	110	150	8.1	303	<2	200	200	<0.2	48	<1	<0.001	0.1	0.25	0.35	0.88	17	0.027	7.2	<0.1	55	<0.01
C7	3	0	330	1580	7.6	4000	180	3390	3570	<0.2	210	7	<0.001	<0.1	3.8	3.8	11	180	0.017	420	<0.1	2010	0.01
C8	0	0	110	150	8.1	300	<2	180	180	<0.2	51	<1	<0.001	<0.1	0.24	0.24	0.88	17	0.029	6.0	<0.1	73	<0.01

Table A-8. Water Analysis for February 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0	X	X	X	7.7	141	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C2	0	0	81	80	7.7	145	<2	110	110	-	22	<1	-	0.022	0.12	0.14	0.74	8.0	<0.01	3.0	<0.1	3	0.024
C3	0	0	120	1560	7.6	2060	-	2160	-	-	440	4	-	0.10	-	-	2.9	140	0.32	20	<0.1	1500	0.039
C4	0	X	X	X	7.9	177	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C5	1	0	140	1990	7.8	2820	<2	2880	2880	X	430	4	X	<0.02	0.01	<0.03	13	230	X	95	X	2000	X
C6	0	X	X	X	7.8	198	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C7	3	0	340	1770	7.5	4010	36	3750	3780	X	-	7	X	<0.02	1.4	1.4	11	170	X	420	X	580	X
C8	0	0	83	130	7.8	272	<2	190	190	-	36	<1	-	0.03	0.22	0.25	0.94	14	0.018	11	<0.1	52	<0.01
C9	5	X	X	X	7.6	1610	X	1500	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C10	4	X	X	X	8.0	1960	X	2200	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C11	0	X	X	X	7.9	213	X	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = Test discontinued as approved by EPA.

Table A-9. Water Analysis for March 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0				7.6	160																	
C2	0	0	100	97	7.6	160	<2	120	120	<1	29	<1	0.001	<0.02	0.25	0.25	0.86	9.0	<0.01	3.3	<0.005	7	<0.01
C3	0	0	94	1510	7.6	1900	<2	1950	1950	<1	440	<4	0.002	0.19	1.1	1.3	2.5	140	0.42	19	<0.005	1475	0.041
C4	0				7.9	250																	
C5	2	0	130	2170	7.7	2500	<2	2570	2570	<1	410	3		<0.02	0.03	0.03	6.4	220		82		1700	
C6	0				8.0	280																	
C7	5	0	310	1770	7.5	4400	6	3820	3826	<1	440	8		<0.02	0.5	0.5	6.0	180		600		595	
C8	0	0	100	170	8.0	280	-	230	-	<1	45	<1	0.001	<0.02	-	-	0.96	17	0.033	6.8	<0.005	61	0.013
C9	4				7.5	1600		1490															
C10	4				8.0	2200		2270															
C11	0				8.1	300		210															

Table A-10. Water Analysis for April 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	0				8.0	180																	
C2	0	0	100	97	7.8	190	<2	120	120	<0.7	30	<1	<0.001	0.025	0.19	0.21	0.76	11	<0.01	3.5	<0.005		0.057
C3	1	0	94	1500	7.4	2000	<2	2080	2080	<0.7		<4	<0.001	0.29	1.0	1.3	2.5	140	0.42	18	<0.005	990	0.073
C4	0				7.4	330																	
C5	1	0	130	2200	7.6	2800	<2	3130	3130	<0.7	440	3			0.02		6.6	280		100		1625	0.014
C6	0				8.2	360																	
C7	4	0	310	1800	7.2	3900	<2	3800		<0.7	390	10					6.2	190		580		850	0.014
C8	0	0	100	170	7.8	410		290	290	<0.7	60	<1	<0.001	0.052	0.31	0.36	1.2	24	0.036	8.9	<0.005	175	<0.01
C9	2				8.0	1300		1120															
C10	8				8.1	2500		2310															
C11	1				8.1	370		300														230	

Table A-11. Water Analysis for May 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	5				8.2	200																	
C2	4	0	120	110	8.1	200	<2	150	150	<0.7	36	1	<0.005	<0.01			0.93	11	0.01	3.6	<0.005	18	<0.01
C3	9	0	57	1700	7.6	2200	<2			<0.7	470	2	<0.005	<0.01	0.21		2.2	160	0.26	13	<0.005	1550	0.052
C4	9				8.2	680																	
C5	9	0	170	2200	8.1	3000	144			<0.7	430	2	<0.005	<0.01	0.18		6.6	280	0.019	63	<0.005	2000	0.020
C6	9				8.3	840																	
C7	6	0	320	2400	7.8	4900	21	4870	4890	<0.7	440	7	<0.005	<0.01			6.7	250	0.014	660	<0.005	590	0.01
C8	8	0	150	540	8.2	1150	<2	820	820	<0.7	170	2	<0.005	<0.01			2.5	63	0.037	4.2	<0.005	480	<0.01
C9	9				8.0	1600																	
C10	9				7.8	2400																	
C11	8				8.2	1000																	

Table A-12. Water Analysis for June 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	12				7.4	110																	
C2	12	0	55	56	7.3	110	270	84	354	<0.7	17	<1	>0.025	0.091	1.3	1.4	0.71	5.6	<0.01	2.4	<0.005	15	<0.01
C3	16	0	63	1620	8.0	2200	<2			<0.7	440	3	<0.005	<0.01	0.17	0.17	2.3	160	0.12	16	<0.005	1350	0.020
C4	14				7.4	240																	
C5	16	0	160	2320	7.4	3200	<2	3320	3320	<0.7	430	3	<0.005	<0.01	0.043	0.04	4.1	290	0.018	95	<0.005	2100	0.015
C6	14				7.6	220																	
C7	No Sample																						
C8	14	0	70	120	7.6	320	7.4				34	<1	<0.005	0.062	0.68	0.74	1.2	12	0.018	7.6	<0.005	80	<0.01
C9	14				8.0	1400																	
C10	14				7.8	1400																	
C11	14				7.8	240																	

Table A-13. Water Analysis for July 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	9				7.7	85																	
C2	9	0	41	43	7.4	85	28			<0.7	22	<1	0.005	0.054	0.059	0.64	0.70	4.2	<0.01	1.8	<0.005	20	0.042
C3	18	0	58	1540	8.0	2100		1310		<0.7	430	3	<0.005	<0.01	0.19	0.19	1.9	140	0.062	17	<0.005	1700	<0.01
C4	14				7.5	130																	
C5	16	0	140	2580	8.2	3600	<2			<0.7	430	4	<0.005	<0.01	0.053	0.05	21	310	0.020	130	<0.005	2500	<0.01
C6	12				7.5	130									0.91								
C7	No Sample																						
C8	12	0	48	67	7.4	140	18			<0.7	24	<1	<0.005	0.044			0.80	6.4	<0.01	3.5	<0.005	83	<0.01
C9	12				8.2	1500																	
C10	13				8.2	1600																	
C11	12				7.8	140																	

Table A-14. Water Analysis for August 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Al mg/ℓ	Ca mg/ℓ	Cl mg/ℓ	Cu mg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Na mg/ℓ	Pb mg/ℓ	SO_4 mg/ℓ	Zn mg/ℓ
C1	17				7.7	170																	
C2	17	5.0	108	270	7.45	170	5	135	140	<0.7	8.5	<1	<0.005	0.06	0.52	0.58	1.5		≤0.01	3.2	<0.1	6	0.02
C3	22	0	66	3600	6.93	1800	<2	1891	1891	<0.7	250	<1	<0.005	0.04	0.093	0.133	4.0	111	0.08	18.1	<0.1	1150	≤0.01
C4	18				7.62	230																	
C5	19	0	202	5500	6.70	3400	<2	3816	3816		200	4	<0.005	≤0.01	0.10	0.1	30	314	≤0.01	155	<0.1	2400	0.03
C6	18*				7.10	170																	
C7		0	986	2800	7.75	4400	710	4019	4729		190	9	<0.005	0.14	25	25.1	25.2	222	0.02	465	<0.1	660	0.02
C8	17	3.0	24	92	6.75	130	<2	73	73	<0.7	15	<1	<0.005	0.07	0.12	0.19	0.7	5.5	≤0.01	4.7	<0.1	54	<0.01
C9	16				7.75	550		1226															
C10	17				8.25	1600		1582															
C11	18				7.59	220		195															

*Very little sample collected - not enough for all tests.

Table A-15. Water Analysis for September 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	7				8.1	120										
C2	8	0	89.6	83.6	8.2	100	3.1	81	84	2	12		<0.7			20
C3	17.5	0	106	1916.2	8.0	2000	<2	2241	2241	3	1470		<0.7			250
C4					8.2	280										
C5	15	0	209	2575	7.9	3300	58	3976	4034	7	2440					220
C6	15				8.2	220										
C7	No Sample															
C8	15	0	101	135.8	8.3	220	<2	167	167	<1	62		<0.7			33
C9	No Sample															
C10	No Sample															
C11	15				8.0	230	3.7									
C13	No Sample															

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<4		<5	0.07	0.22	0.29	<0.5	1.5	6.6	0.01	<0.2	3.5		<100		<100
C3	<4		<5	<0.02	0.09	0.09	0.8	6.0	131	0.06	<0.2	23		<100		<100
C4					0.05											
C5	<4			<0.02	0.15	0.15	<0.5	31	290		<0.2	160				
C6					0.20											
C7																
C8	<4		<5	0.05	0.21	0.26	1.3	2.4	11.7	0.02	<0.2	9		<100		<100
C9																
C10																
C11					0.32											
C13																

Table A-16. Water Analysis for October 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	5.5				7.87	180										
C2	4.5	0	76.2	80	8.02	180	<2	73	73	<1	12		<0.1	0.3	<0.1	
C3	12.5						3	2406	2409	3	1520		<0.1	0.3		
C4	3.5				7.94	230										
C5	5	0	170	2627	7.85	3700	73	4022	4030	4	2420			0.4	<0.1	
C6	2.5															
C7	No Sample															
C8	2.5	0	83.1	132	7.8	290	2.7	171	174	<1	40		<0.1	0.3	<0.1	
C9	5.5				7.81	1060										
C10	5				7.73	2040										
C11	2.5	0	194	139	7.97	310	<2	168	168	1	54		<0.1	0.3	<0.1	
C13	11.5	0	229	369	7.85	700	4.8			3	118		<0.1	0.9	<0.1	

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<2.5		<50	0.08	0.12	0.2	<1	1.5	6.9	<0.05	<0.2	3.2		<200	0.4	<10
C3	<2.5		<50	0.05	0.14	0.2	<1	7	138	<0.05	<0.2	21		<200	<0.2	30
C4																
C5	<2.5			<0.05	0.1	0.1	<1	31	300		<0.2	150			11	
C6																
C7																
C8	<2.5		<50	0.15	0.2	0.35	<1	2.1	11.5	<0.05	<0.2	8.5		<200	<0.2	<10
C9																
C10																
C11	<2.5		<50	0.10	0.22	0.3	<1	<1	10	<0.05	<0.2	7.5		<200	0.2	<10
C13	<2.5		<50	<0.05	0.6	0.6	<1	6	30	0.5	<0.2	17		<200	0.2	<10

Table A-17. Water Analysis for November 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	1				7.4	158										
C2	0.5	0	166	84	7.5	158	<2	69	69	<1	11	0.08	<1	0.3	<0.1	20
C3	6	0	240	1725	7.4	2500	<2	2378	2378	<1	1600	<0.06	<1	0.4	<0.1	160
C4	1				7.6	210										
C5	2	0	329	2735	7.5	3800	6.8	3344	3350	10	2480	0.08		0.3	<0.1	300
C6	0				7.3	240										
C7	4	0	720	1780	6.9	4800	151.3	4491	4642	9		5.1		5.8	<0.1	230
C8	0	0	197	174	7.2	390	4.1	246	250	<1	116	0.11	<1	0.3	<0.1	26
C9	3.5				7.4	1580										
C10	2.5				7.6	2400										
C11	0	0	183	125	7.5	240	1.1	197	198	<1	64	0.09	<1	0.3	<0.1	24
C13	4	0	649	387	7.5	650	2.6	453	456	8	120	0.12	<1	0.8	<0.1	84

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	35	0.078	0.09	0.17	<1	0.92	5.6	<0.02		3.2	<5	<5	0.2	22
C3	<5	<5	<5	<0.02	0.07	0.07	<1	3.1	56	0.10		27	6	<5	0.3	50
C4																
C5	<3	<5		0.19	0.09	0.28	<1	9.4	200			140	8		14	
C6																
C7	<5	6		<0.02	3.6	3.6	<1	5.1	100			530	14		1.3	
C8	<5	<5	14	0.067	0.13	0.20	<1	1.5	10	0.02		21	8	<5	0.3	14
C9																
C10																
C11	<5	<5	<5	0.068	0.11	0.18	1	1.2	9.8	0.03		7.4	19	28	0.4	<5
C13	<5	<5	9	0.082	0.75	0.84	1	2.8	38	0.81		17	10	<5	0.2	14

Table A-18. Water Analysis for December 1975.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	0				6.4	170										
C2	0	0	77	101	6.5	160	<2	129	129	<0.5	<0.5	<0.06	<1	0.3	<0.1	19
C3	0	0	26	1502	7.0	1800	<2	2081	2081	4	1520	0.06	<1	<0.3	<0.1	470
C4	0				6.8	220										
C5	1	0	161	2331	7.2	2600	2	3189	3191	4	2130	<0.06		<0.3	<0.1	290
C6	0				7.5	230										
C7	0	0	842	2101	7.0	3900	34	4039	4073	8	820	<0.06		<0.3	<0.1	440
C8	0	0	83	94	7.4	250	4	192	196	<0.5	18	0.06	<1	<0.3	<0.1	30
C9	0				6.0	1300	74									
C10	0				6.9	1800	<2	2186	2186							
C11	0	0	89	157	7.1	250	2	197	199	0.5	38	0.06	<1	<0.3	<0.1	32
C13	0	0	89	394	7.5	500	2	514	516	3		0.06	<1	1.0	<0.1	85

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	<5	0.043	0.09	0.13	<0.5	0.98	7.2	0.031		4.3	12	<5	<0.2	20
C3	<5	<5	<5	0.26	0.2	0.46	<0.5	2.9	110	0.40		17	23	<5	<0.2	28
C4																
C5	<5	<5		<0.02	0.08	0.03	<0.5	7.2	160			120	19		8.7	
C6																
C7	<5	9		0.20	0.5	0.70	<0.5	11	140			330	12		1.1	
C8	<5	<5	41	0.54	0.22	0.76	<0.5	1.3	12	0.044		8.0	<10	<5	<0.2	<5
C9																
C10																
C11	<5	<5	8	0.79	0.17	0.96	<0.5	1.2	13	0.18		10	<10	9	<0.2	52
C13	<5	<5	<5	0.16	0.44	0.60	<0.5	2.6	30	0.53		22	<10	<5	<0.2	8

Table A-19. Water Analysis for February 1976.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	0				7.91	150										
C2	0	0	88	82	7.72	150	4.7	125	130	<0.5	14	<0.01	<1	<0.3	<0.1	23
C3	0	0	130	1360	7.2	2500	2.7	1700	1703	4.0	1320	<0.01	<1	0.4	<0.1	390
C4	0				7.59	220										
C5	0	0	167	2010	7.47	4000	6.7	3335	3342	4.0	2150	<0.01		<0.3	<0.1	450
C6	0				7.70	230										
C7	0	0	390	1918	6.91	5010	142.1	4105	4247	8.0	860	<0.01		<0.3	<0.1	490
C8	0	0	96	162	7.41	310	1.7	221	223	0.5	70	<0.01	<1	<0.3	<0.1	39
C9	0				7.52	1600	3.1	1205	1208							
C10	1				7.9	2700	1.5	2128	2130							
C11																
C13	0	0	3.0	331	7.56	740	1.9	363	365	3.0	80	<0.01	<1	0.4	<0.1	85

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	<5	0.061	0.23	0.29	<0.2	1.2	2.7	<0.02		3.2	<5	<50	<0.2	13
C3	<5	7	58	0.052	0.20	0.27	<0.2	3.2	120	0.48		22	13	<50	0.2	72
C4																
C5	<5	7		0.10	0.06	0.16	<0.2	13	270			140	6		9.3	
C6																
C7	<5	21		0.12	2.5	2.6	<0.2	11	180			480	10		1.0	
C8	<5	<5	<5	0.05	0.11	0.16	<0.2	1.2	13	0.068		12	<5	<50	0.3	16
C9																
C10																
C11																
C13	<5	<5	<5	<0.02	0.45	0.45	<0.2	2.4	29	0.63		15	<5	<50	0.3	13

Table A-20. Water Analysis for March 1976

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	0				7.0	200										
C2	0	0	88	91	7.4	200	2.9	176	179	1	12	<0.01		<0.3	<0.1	24
C3	0	0	72	1293	7.0	5600	3.9	1770	1774	4.5	1260	<0.01		<0.3	<0.1	320
C4	0				7.5	360										
C5	0	0	121	1979	7.3	3500	8.6	2854	2863	3	1900	<0.01		<0.3	<0.1	390
C6																
C7																
C8																
C9	0				7.5	1900	328	1330	1658							
C10	0				7.6	3000	4.6	2528	2533							
C11																
C13	0	0	243	349	7.4	760	14.6	429	444	5	100	<0.01		0.4	<0.1	77

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	10	1.1	0.1	1.2	0.05	1.2	9.0	0.034		2.3	13	<5	<0.2	5
C3	<5	<5	<5	0.37	1.2	1.6	0.05	2.8	110	0.66		19	43	<5	0.3	130
C4																
C5	<5	<5		1.2	0.1	1.3	0.08	9.4	190			68	19		>10	
C6																
C7																
C8																
C9																
C10																
C11																
C13	<5	<5	<5	0.02	1.0	1.0	0.05	2.4	34	0.65		13	<5	<5	0.2	<5

Table A-21. Water Analysis for April 1976.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	0				7.63	150										
C2	0		110	131	7.52	170	9.5	147	157	0.5	5	<0.01		<0.3		0.23
C3	1		72	1347	7.01	1900	4.1	1871	1875	3.0	1040	<0.01		<0.3		320
C4	2				7.82	480										
C5	4.5		150	2208	7.69	2900	1.9	3153	3155	4.0	2180	<0.01		<0.3		43
C6	0				7.89	680										
C7	3		405	1998	7.0	4100	20.8	4107	4128	9.5	2620	<0.01		<0.3		
C8	0		126	418	7.81	640	5.5	509	515	1.0	250	<0.01		<0.3		
C9	2				7.14	1500	19.4	1235	1254							
C10	8.5				7.48	2600	3.5	2537	2541							
C11																
C13	0.5		287	349	7.68	680	1.2	441	442	5	20	<0.01		0.4		62

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	<5	<0.02	0.41	0.41	<0.03	0.83	8.2	<0.02		3.4	7	<5	0.3	7
C3	<5	<5	20	0.057	1.15	1.21	<0.03	2.7	110	0.52		19	34	<5	0.6	100
C4																
C5	<5	<5		<0.02	0.02	0.02	0.03	12	260			64	29		23	
C6																
C7					0.58		<0.03								7.4	
C8					0.24		<0.03								1.2	
C9																
C10																
C11																
C13	<5	<5	6	<0.02	0.48	0.48	<0.03	2.5	37	0.17		16	<5	<5	0.4	6

Table A-22. Water Analysis for May 1976.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	9				7.9	135										
C2	9		76	251	7.9	135	2.5	129	132	2	<5	<0.01		<0.3		57
C3	13		68	1653	7.9	2300	<2	2327	2327	3	1780	<0.01		<0.3		440
C4	12				8.0	270										
C5	14		190	2390	8.0	3600	3.2	3748	3151	4	2400	<0.01		<0.3		510
C6	12				8.2	340										
C7	7		361	1969	7.0	4400	66.8	4550	4617	7	2680	0.05		<0.3		540
C8	10		205	236	8.1	460	7.3	376	383	<0.5	172	0.02		<0.3		63
C9	13				8.3	1700	<2	1490	1490							
C10	15				7.9	2200	<2	2209	2209							
C11	12		91	187	8.1	370	<2	288	288	<0.5	112	<0.01		<0.3		44
C13	11		226	280	8.1	480	<2	471	471	3	12	<0.01		<0.3		64

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	13	0.08	0.40	0.48	0.05	0.74	5.6	0.026		3.2	<5	<5	0.3	23
C3	<5	<5	12	<0.02	0.15	0.15	0.10	2.9	75	0.24		16	16	<5	0.6	38
C4																
C5	<5	<5		0.026	0.04	0.06	0.14	14	61			110	21		20	
C6																
C7	<5	<5		<0.02	2.15	2.2	0.11	12	85			510	<5		16	
C8	<5	<5	12	0.059	0.29	0.35	0.10	1.3	24	<0.02		21	<5	<5	0.9	9
C9																
C10																
C11	<5	<5	<5	0.026	0.27	0.30	0.02	1.2	6.9	0.022		9.1	<5	<5	0.4	10
C13	<5	<5	10	<0.02	0.23	0.23	0.04	1.8	2.4	0.048		11	<5	<5	0.5	6

Table A-23. Water Analysis for June 1976.

Sample	Temp °C	Acidity mg $CaCO_3$/ℓ	Alkalinity mg $CaCO_3$/ℓ	Hardness Total mg/ℓ	pH	Specific Conductance μ mhos	Suspended Solids mg/ℓ	Total Dissolved Solids mg/ℓ	Total Solids mg/ℓ	Cl mg/ℓ	SO_4 mg/ℓ	PO_4 mg/ℓ	Al mg/ℓ	As μg/ℓ	B mg/ℓ	Ca mg/ℓ
C1	11.5				8.1	86										
C2	11.5		61	58	7.9	86	24	40	64	<0.5	9	<0.01		0.5		12
C3	16		83	1453	7.9	2000	5	2103	2108	3.0	1310	<0.01		<0.3		380
C4	5.0				8.0	120										
C5	10		170	2847	7.8	3500	6	3595	3601	4.0	1610	<0.01		<0.3		190
C6	7.8				8.0	130										
C7																
C8	7.5		61	182	7.7	150	62	52	114	0.5	12	<0.01		0.6		18
C9	13.0				7.7	1600	31	1411	1442							
C10	11.4				8.0	150	3	1505	1508							
C11	8.5		55	131	8.1	140	72	82	154	<0.5	52	<0.01		0.3		17
C13	13.0		198	312	8.0	400	8	218	226	2.0	160	<0.01		0.6		52

	Cd μg/ℓ	Cr μg/ℓ	Cu μg/ℓ	Fe dis mg/ℓ	Fe undis mg/ℓ	Fe total mg/ℓ	Hg μg/ℓ	K mg/ℓ	Mg mg/ℓ	Mn mg/ℓ	Mo mg/ℓ	Na mg/ℓ	Ni μg/ℓ	Pb μg/ℓ	Se μg/ℓ	Zn μg/ℓ
C1																
C2	<5	<5	10	0.078	0.45	0.53	<0.03	0.44	3.6	<0.02		1.9	<5	<5	0.2	23
C3	6	<5	7	0.033	0.09	0.12	<0.03	2.2	30	0.07		17	6	<5	0.6	10
C4																
C5	10	<5		0.047	0.06	0.11	0.08	11	77			110	12		6.7	
C6																
C7																
C8	<5	<5	27	0.072	1.35	1.42	<0.03	0.61	2.7	0.024		5.4	<5	<5	0.4	8
C9																
C10																
C11	<5	<5	6	0.055	1.2	1.26	<0.03	0.53	1.4	<0.02		3.0	<5	<5	0.3	<5
C13	<5	<5	5	<0.02	0.24	0.24	0.04	1.4	19	0.026		10	<5	<5	0.4	<5

Appendix B

Water Quality Data - Daily Samples

Table B-1

1975 Daily TDS Concentrations (mg/ℓ)

Date	Station C2	C3	C5	C6	C9	C10	C13
Mar 31	113	1770	2790	260	1100	2250	
Apr 7	119	1310	2150	360	1080	2300	
9	108	1400	2250	380	975	2010	
11	100	1390	1900	420	950	2010	
13	103	1310	1890	520	960	2030	
15	100	1200	1750	520	750	2030	
17	130	1300	2250	590	1150	2260	
19	130	1460	2500	750	1250	2490	
21	128	1380	2390	650	1640	2510	
23	132	1500	2490	650	1580	2490	
25	128	1710	2490	660	1600	2500	
27	120	1800	2490	750	1550	2510	
29	140	2000	2740	910	1580	2600	
May 2	112	2030	3080	700	1440	2300	
4	122	2080	2790	590	1370	2200	
6	122	2060	2640	700	1570	2180	
8	129	2070	3200	650	1380	2300	
10	124	2030	2690	520	1450	2290	
12	110	2030	2850	420	1370	2180	
14	104	2000	2770	390	1370	2100	
22	95	1940	3000	260	1190	1370	
29	90	1920	3000	235	1190	1210	
Jun 5	70	2100	3200	145	1300	1210	
13	64	2000	3400	120	1400	1320	
20	54	1980	3400	90	1380	1240	
27	43	1790	3080	76	1200	1300	
Jul 3	56	1880	3400	89	1250	1400	
11	70	1830	3460	100	1260	1560	
17	91	1700	3420	130	1260	1500	420
25	131	1780	3210	205	1300	1480	450
Aug 1	139	1700	3550	170	1300	1600	445
7	156	1410	4050	230	1300	1640	445
14	113	1290	3550	175	1240	1650	450
21	111	1870	3550	170	1280	1680	455
28	106	1900	3420	178	1300	1710	455
Sep 5	118	2000	3550	178	1250	1700	460
13	112	2010	3450	200	1260	1765	455
21	95	2100	3600	147	1240	1760	480
28	83	1800	3300	120	1100	1760	460
Oct 3	-	1880	3300	147	1100	1670	-
4	91	-	-	-	-	-	480
10	90	1880	3190	158	1090	1720	470
17	90	1880	3300	162	1120	1720	470
24	119	2100	3380	235	1200	1800	480
31	95	2100	3440	160	1240	1870	480
Nov 7	93	2100	3520	148	1240	1880	500
21	110	1831	2741	169	1088	1730	532
26	105	1811	2741	164	1042	1730	512
Dec 5	117	1639	2741	164	1088	1693	477

Table B-2

1976 Daily TDS Concentrations (mg/ℓ)

Date	Station C2	C3	C5	C6	C9	C10	C13
Mar 22	113	1459	1215	-	-	-	-
23	-	-	-	-	1150	2040	467
25	95	1229	1890	299	1021	2014	404
27	112	1395	2130	399	1010	1990	451
30	114	1431	2173	260	972	1782	427
Apr 1	98	1271	1270	326	874	1977	402
3	96	1092	1183	398	761	1947	436
6	107	1055	2088	519	1020	1876	508
9	98	1200	2068	510	880	1869	451
11	110	1193	2547	421	1128	1940	421
13	103	1416	2381	419	1183	1866	441
15	107	1551	2483	421	1193	1832	461
17	105	1622	2622	428	1198	1853	450
20	108	1656	2444	393	1225	1848	440
22	105	1706	2578	344	1267	1856	421
25	106	1699	2629	313	1243	1832	385
27	107	1763	2712	325	1230	1816	367
29	96	1657	2649	291	1202	1763	357
May 2	94	1688	2697	247	1183	1721	359
4	87	1706	2783	225	1193	1706	349
6	82	1706	2771	210	1210	1673	335
8	82	1705	2547	218	1183	1627	317
11	73	1627	2512	218	1092	1463	284
13	80	1640	2570	185	1160	1418	293
16	74	1657	2649	170	1159	1422	278
18	67	1657	2699	137	1126	1372	261
21	63	1673	2678	121	1180	1357	288
24	61	1657	2345	107	1165	1330	273
26	61	1621	2610	113	1176	1314	274
28	55	1640	2737	93	1205	1289	274
31	53	1692	2764	89	1205	1281	282
Jun 2	48	1657	2871	94	1188	1291	284
4	42	1681	2718	66	1168	1301	278

Appendix C

Water Quality Data - Supplementary Stations

Table C-1

Description of Stations

Station	Description
#20	Ground water seep on natural ground
#21	C10 stream above clogged culvert
#22	Ground water flowing from spoils near Station C10 but not flowing through the discharge monitoring station
#23	Ground water seep from base of spoils along Trout Creek
#24	Ground water seep from base of spoils along Trout Creek
#25	Combination of C9 and C10 water due to clogged culvert
#26	C9 water before joining C10 water at #25
#27	C10 water before joining C9 water at #25

Table C-2

TDS Concentrations (mg/ℓ)

	Station							
Date	#20	#21	#22	#23	#24	#25	#26	#27
Apr 24	158	173	2836	4772	3900	477	993	-
May 18	-	-	-	3966	-	-	-	-
20	-	127	2572	-	-	192	1027	137
24	-	-	-	4088	-	-	-	-
28	-	-	-	3974	-	-	-	-

Appendix D

Water Quality Data - Experimental Plots

Table D-1

Chemical Analyses of Water Samples

Sample No.*	pH	Cond	Na	Ca	Mg	K	HCO_3	CO_3	SO_4	NO_3	Cl
T-2/900-716	7.9	200	0.1	1.0	0.7	0.1	1.5	0	0.7	<0.01	<0.1
SS-2/948-716	7.8	3900	6.5	22.1	28.6	0.7	6.5	0	55.5	0.03	<0.1
SS-2/1000-716	7.4	4200	5.9	27.5	34.0	0.7	5.9	0	58.4	0.02	<0.1
SS-2/1320-716	7.3	3400	4.7	19.9	22.9	0.6	5.6	0	45.3	0.02	0.3
SS-2/1320-716	7.3	3400	4.1	21.2	24.7	0.6	4.8	0	42.8	0.01	<0.1
SS-2/855-717	7.5	4600	7.8	26.6	36.6	0.8	6.4	0	60.9	0.03	0.1
SS-2/740-718	7.6	4600	8.3	26.4	38.6	0.8	6.7	0	62.5	0.03	0.1
SS-2/740-718	7.7	4600	8.5	27.4	36.8	0.8	6.6	0	62.4	0.03	0.3
T-3/1130-721	8.3	200	0.1	1.2	0.8	0.1	1.9	0	0.8	<0.01	<0.1
S-3/1240-721	7.7	700	0.7	3.2	2.6	0.2	2.2	0	4.8	0.01	<0.1
S-3/1315-721	7.3	300	0.2	1.3	1.0	0.1	1.4	0	1.1	<0.01	0.1
S-3/1403-721	8.2	200	0.1	1.3	0.9	0.1	1.5	0	1.0	<0.01	0.1
SS-3/1415-721	7.0	2400	1.0	17.4	13.7	0.6	3.4	0	30.5	<0.01	0.1
SS-3/1505-721	7.0	3000	1.6	22.9	19.4	0.6	4.6	0	36.7	0.06	0.1
T-3/1515-721	7.9	300	0.1	1.3	0.9	0.1	1.8	0	0.8	<0.01	<0.1
SS-3/1930-721	7.9	3400	3.8	25.4	23.8	0.6	5.3	0	43.0	0.08	0.1
T-4/0830-722	8.3	300	0.2	1.3	0.9	0.7	1.9	0	0.9	<0.01	0.7
S-4/1225-722	8.1	300	0.1	1.3	0.9	0.1	1.9	0	0.8	<0.01	<0.1
SS-4/1339-722	7.1	2800	2.2	19.9	15.4	0.6	3.4	0	37.5	0.02	0.1
SS-4/1435-722	7.3	3600	4.8	23.7	24.5	0.7	4.3	0	43.8	0.05	<0.1
SS-4/1515-722	7.3	3600	4.1	24.1	24.7	0.8	4.8	0	49.2	0.06	<0.1
SS-4/1717-722	7.2	3600	4.7	24.4	26.8	0.8	4.5	0	49.2	0.05	<0.1
SS-4/2040-722	7.3	3600	4.6	25.1	23.2	0.7	4.4	0	44.5	0.04	0.1
S-5/1003-731	7.7	500	0.2	3.2	2.0	0.2	1.8	0	3.6	<0.01	<0.1
T-5/1025-731	8.3	200	0.2	1.3	1.4	0.1	1.7	0	0.7	<0.01	<0.1
S-5/1033-731	8.3	400	0.2	2.2	1.8	0.1	2.0	0	1.8	<0.01	<0.1
S-5/1115-731	8.1	400	0.2	2.2	1.8	0.1	2.0	0	1.9	<0.01	<0.1
SS-5/1200-731	7.3	1400	0.4	7.2	8.2	0.4	2.8	0	12.8	0.01	<0.1
SS-5/1220-731	7.2	2600	1.5	17.9	13.7	0.6	4.0	0	30.4	0.02	<0.1
SS-5/1300-731	7.1	2900	4.0	19.9	19.2	0.6	4.5	0	40.8	0.02	<0.1
SS-5/1348-731	7.2	3200	2.6	21.0	21.5	0.6	4.4	0	42.6	0.02	<0.1
SS5/1458-731	7.2	3500	2.4	22.0	24.8	0.7	4.5	0	46.1	0.02	<0.1
SS-5/1910-731	7.4	3700	3.9	23.0	28.7	0.7	4.8	0	48.3	0.02	<0.1
T-5/1910-731	8.9	200	0.2	1.3	1.5	0.1	1.8	0	0.8	<0.01	<0.1
SS-5/0915-81	8.0	3700	2.4	24.7	31.9	0.7	4.7	0	55.4	0.02	<0.1
T-6/0935-806	8.4	300	0.2	1.7	1.2	0.05	2.3	0	1.0	0.01	<0.1
S-6/0957-806	7.5	300	0.3	2.1	1.3	0.09	2.3	0	1.4	<0.01	<0.1
S-6/1017-806	7.3	300	0.3	1.9	1.2	0.07	2.8	0	1.4	0.01	<0.1
SS-6/1100-806	7.4	4900	10.6	25.4	40.0	0.8	6.9	0	65.1	0.26	<0.1
S-6/1102-806	7.7	300	0.3	1.9	1.3	0.06	2.6	0	1.2	<0.01	<0.1
SS-6/1133-806	7.5	3800	6.7	21.1	27.9	0.8	5.4	0	48.2	0.13	<0.1
SS-6/1215-806	7.1	4100	6.2	22.2	27.9	0.8	5.6	0	46.9	0.12	<0.1
SS-6/1325-806	7.1	4100	8.1	23.2	31.0	0.9	6.6	0	54.7	0.14	<0.1
SS-6/1515-806	7.1	4500	10.1	23.8	34.4	0.9	7.0	0	62.4	0.16	<0.1
SS-6/0815-807	7.4	4900	11.2	24.6	39.2	0.9	7.9	0	65.6	0.19	<0.1
T-7/0800-808	8.1	400	0.2	2.1	1.5	0.05	2.9	0	1.1	0.01	<0.1

Table D-1 (Cont'd)

Sample No.*	pH	Cond	Na	Ca	Mg	K	HCO_3	CO_3	SO_4	NO_3	Cl
S-7/0915-808	7.4	400	0.3	2.1	1.5	0.07	2.4	0	1.6	0.01	<0.1
S-7/0915-808	7.6	400	0.3	2.4	1.5	0.10	2.5	0	1.9	0.02	<0.1
S-7/1024-808	7.9	400	0.3	2.1	1.4	0.06	2.4	0	1.6	0.01	<0.1
SS-7/1125-808	7.5	3000	3.7	20.3	17.2	0.6	4.6	0	36.7	0.41	<0.1
SS-7/1240-808	7.3	2500	1.2	16.3	13.8	0.6	3.8	0	26.0	0.15	<0.1
SS-7/1400-808	7.4	2400	1.3	15.8	13.8	0.5	4.0	0	26.0	0.19	<0.1
S-8/0943-811	7.6	300	0.3	2.0	1.2	0.09	2.3	0	1.4	0.01	<0.1
T-8/1000-811	7.9	300	0.2	2.0	1.4	0.05	2.6	0	1.1	0.02	<0.1
S-8/1127-811	7.8	300	0.2	1.7	1.1	0.07	2.3	0	1.0	0.01	<0.1
S-8/1146-811	8.0	300	0.3	1.9	1.2	0.06	2.3	0	1.3	0.01	<0.1
SS-8/1305-811	7.2	2000	1.4	13.4	11.2	0.5	3.4	0	23.4	0.11	<0.1
SS-8/1345-811	7.2	2600	2.9	15.7	14.5	0.6	4.1	0	31.2	0.14	<0.1
SS-8/1515-811	7.3	2900	4.0	18.2	17.8	0.6	4.6	0	32.6	0.18	<0.1
SS-8/1925-811	7.3	2700	3.9	17.0	18.8	0.6	4.6	0	33.8	0.14	<0.1
T-9/1000-813	8.1	300	0.2	1.7	1.2	0.05	2.2	0	1.0	0.01	<0.1
S-9/1012-813	7.5	400	0.3	2.6	1.5	0.15	2.4	0	2.3	0.03	<0.1
S-9/1032-813	7.9	300	0.3	2.0	1.3	0.09	2.3	0	1.5	0.01	<0.1
SS-9/1102-813	7.2	700	0.4	4.0	3.2	0.2	2.6	0	5.3	<0.01	<0.1
S-9/1111-813	7.9	300	0.3	1.9	1.3	0.07	2.3	0	1.4	0.01	<0.1
SS-9/1143-813	7.3	1700	1.3	9.8	9.4	0.4	3.5	0	18.8	0.05	<0.1
SS-9/1250-813	7.3	2900	3.7	18.5	18.4	0.6	4.8	0	35.8	0.09	<0.1
SS-9/1440-813	7.3	3300	4.6	20.4	21.2	0.7	4.6	0	40.4	0.07	<0.1
SS-9/1530-813	7.3	3500	5.3	20.8	23.0	0.7	4.9	0	45.0	0.09	<0.1
SS-9/1915-813	7.7	4100	6.2	22.0	25.2	0.8	4.9	0	50.0	0.11	<0.1
T-10/1115-815	7.7	300	0.2	1.7	1.1	0.17	2.3	0	1.0	0.01	<0.1
S-10/1158-815	7.4	400	0.3	2.6	1.6	0.12	2.3	0	2.4	0.01	<0.1
S-10/1225-815	7.8	300	0.2	1.9	1.2	0.08	2.1	0	1.4	0.01	<0.1
S-10/1310-815	7.9	300	0.2	1.8	1.1	0.07	2.1	0	1.3	<0.01	<0.1
SS-10/1410-815	7.1	2500	1.2	16.4	15.0	0.6	4.4	0	29.9	0.11	<0.1
SS-10/1455-815	7.2	2600	1.5	18.2	15.8	0.6	4.7	0	31.2	0.23	<0.1
SS-10/1545-815	7.2	3000	2.8	19.0	19.8	0.6	5.3	0	33.8	0.28	<0.1
S-11/0845-819	7.6	300	0.2	1.8	1.2	0.2	2.4	0	1.2	<0.01	0.1
S-11/0908-819	7.8	300	0.2	1.6	1.1	0.2	2.3	0	1.2	<0.01	0.1
T-11/0945-819	8.0	300	0.2	1.6	1.0	0.2	2.4	0	0.9	<0.01	<0.1
SS-11/0950-819	7.6	3600	5.2	18.4	27.0	0.7	7.3	0	45.6	0.05	0.1
S-11/0954-819	7.9	300	0.2	1.6	1.1	0.2	2.4	0	1.2	<0.01	0.1
SS-11/1125-819	7.6	3900	4.5	20.7	27.5	0.8	6.1	0	49.5	0.05	0.1
SS-11/1230-819	7.6	4200	5.4	22.1	32.3	0.8	6.9	0	54.7	0.07	0.1
S-11/1235-819	7.7	300	0.2	1.8	1.2	0.2	2.6	0	1.2	0.01	0.1
SS-11/1445-819	7.4	4600	7.8	23.1	34.8	0.9	7.3	0	58.6	0.1	0.1
SS-11/1855-819	7.7	4600	7.0	23.4	35.6	1.0	8.0	0	60.8	0.08	0.1
SS-11/0750-820	7.9	4600	8.1	23.4	37.7	1.0	8.1	0	59.4	0.06	0.1
T-12/1115-820	7.6	300	0.2	1.5	1.0	0.2	2.3	0	0.8	0.01	<0.1
S-12/1150-820	7.7	400	0.2	2.4	1.4	0.2	2.4	0	2.0	0.02	0.1
S-12/1215-820	7.8	600	0.2	2.1	1.3	0.2	2.6	0	1.4	0.01	0.1
SS12/1234-820	7.5	3200	3.7	19.2	22.5	0.6	5.0	0	44.3	0.16	0.1
S-12/1259-820	7.8	400	0.2	1.9	1.2	0.2	2.6	0	1.4	0.01	0.1
SS-12/1355-820	7.6	2700	2.8	15.3	17.4	0.6	4.5	0	30.4	0.06	0.1
SS-12/1508-820	7.7	3200	3.6	17.6	20.4	0.6	4.4	0	40.4	0.06	0.1
SS-12/1625-820	7.7	3300	4.3	18.9	22.0	0.7	4.7	0	40.4	0.09	0.1

Table D-1 (Cont'd)

Sample No.*	pH	Cond	Na	Ca	Mg	K	HCO_3	CO_3	SO_4	NO_3	Cl
SS-12/2045-820	7.7	3600	4.8	20.6	23.6	0.7	5.0	0	44.3	0.07	0.1
T-13/0970-821	8.0	300	0.2	1.5	1.0	0.2	2.3	0	0.8	0.01	<0.1
S-13/1017-821	7.7	400	0.2	1.8	1.1	0.2	2.4	0	1.0	0.01	0.1
S-13/1017-821	7.6	400	0.2	2.6	1.4	0.2	2.3	0	2.5	0.01	0.1
SS-13/1050-821	7.5	2600	2.7	17.0	16.0	0.5	4.8	0	31.2	0.07	0.1
S-13/1055-821	7.9	300	0.2	1.8	1.1	0.2	2.4	0	1.2	0.01	0.1
S-13/1117-821	7.9	300	0.2	1.6	1.0	0.2	2.1	0	1.0	0.02	<0.1
SS-13/1145-821	7.4	2800	2.8	17.4	18.1	0.6	4.7	0	35.2	0.14	<0.1
SS-13/1215-821	7.8	3000	3.0	18.2	18.3	0.6	4.5	0	36.4	0.16	0.1
SS-13/1304-821	7.5	3200	3.2	18.7	19.8	0.6	4.9	0	39.1	0.19	<0.1
SS-13/1355-821	7.8	3200	3.4	19.4	20.1	0.6	4.9	0	39.1	0.21	<0.1
SS-13/1508-821	7.7	3200	3.4	19.7	20.0	0.6	5.0	0	37.8	0.21	<0.1

*Sample No. indicates type of sample (S=surface, SS=subsurface, T=water supply in tank), run number, time, and date (month and day).

Appendix E

Discharge Data

Table E-1

Mean Daily Discharges, 1975

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Mar 28	-	2.5	-	1.1	3.7
29	-	2.5	-	1.1	3.4
30	-	2.5	-	0.9	3.4
31	0.29	2.5	0.52*	0.9	3.1
Apr 1	0.29	2.5	0.52	0.9	3.1
2	0.30	2.8	0.52	0.9	2.8
3	0.31	3.1	0.54	0.6	2.8
4	0.33	3.4	0.55	0.6	3.1
5	0.34	4.0	0.57	0.6	3.4
6	0.35	4.5	0.58	0.6	4.0
7	0.37	4.8	0.60*	0.9	4.8
8	0.37	4.2	0.54	0.9	5.1
9	0.37	3.4	0.49*	0.9	5.4
10	0.34	3.4	0.51	0.9	5.4
11	0.31	4.2	0.52*	1.1	5.9
12	0.34	4.8	0.58	1.7	6.8
13	0.37	5.7	0.64*	1.7	7.6
14	0.37	6.2	0.67	1.1	9.1
15	0.37	7.6	0.68*	2.0	11.0
16	0.37	10.2	0.72	2.3	17.0
17	0.36	12.5	0.74*	1.1	29.2
18	0.36	11.6	0.67	0.9	32.9
19	0.36	9.9	0.60*	0.9	27.2
20	0.38	9.4	0.69	2.0	23.5
21	0.44	12.5	0.84*	7.1	22.9
22	0.53	14.2	0.94	12.2	28.6
23	0.62	18.7	0.99*	19.3	39.1
24	0.65	22.4	1.16	36.8	53.0
25	0.80	26.3	1.45*	62.9	58.3
26	0.82	32.9	1.38	83.8	68.8
27	0.74	39.1	1.25*	81.3	74.8
28	0.60	41.6	1.13	62.0	60.9
29	0.52	42.5	1.06*	43.3	44.5
30	0.49	42.2	0.95	31.2	32.9
May 1	0.45	41.3	0.88	26.3	25.8
2	0.49	39.4	0.85*	25.2	21.8
3	0.60	37.4	0.99	29.5	21.2
4	0.69	37.4	1.11*	39.1	30.9
5	0.63	38.5	1.05	44.5	45.0
6	0.55	39.1	0.95*	36.5	39.4
7	0.52	40.8	0.90	25.8	30.9
8	0.54	43.0	0.90*	22.4	25.8
9	0.65	38.8	1.03	20.7	23.8
10	0.84	42.5	1.27*	24.6	24.9

Table E-1 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
May 11	1.12	56.9	1.52	32.0	32.9
12	1.20	70.8	1.57*	41.1	39.1
13	1.18	51.0	1.53	40.5	41.6
14	1.70	42.8	2.01*	38.8	44.2
15	2.31	42.5	2.66	36.8	57.5
16	2.64	42.5	3.00	36.5	62.0
17	3.12	45.0	3.51	34.6	60.3
18	2.93	47.9	3.35	34.6	56.6
19	2.93	52.4	3.38	36.8	47.3
20	3.71	60.9	4.19	34.6	44.5
21	3.63	69.7	4.13	30.3	42.5
22	3.43	77.6	3.95*	26.1	41.6
23	3.12	49.3	3.64	24.9	38.5
24	2.92	45.6	3.44	24.6	33.1
25	2.69	41.9	3.21	24.1	30.3
26	2.46	39.1	2.99	23.8	28.9
27	2.18	36.0	2.71	23.2	28.3
28	1.93	33.4	2.46	22.7	28.3
29	1.69	30.9	2.22*	22.1	28.3
30	1.49	23.5	2.02	20.1	26.3
31	1.66	13.6	2.19	19.0	25.2
Jun 1	2.12	20.4	2.66	17.8	24.4
2	2.55	20.4	3.08	16.7	24.9
3	2.83	20.1	3.37	15.9	24.6
4	3.26	19.0	3.80	15.6	22.1
5	3.64	18.1	4.18*	15.0	19.5
6	4.06	18.4	4.77	14.7	19.3
7	7.13	18.4	8.05	15.0	18.4
8	9.92	18.4	10.98	15.6	20.4
9	8.62	18.4	9.87	14.4	20.4
10	4.46	18.1	5.85	13.9	19.5
11	3.27	18.1	4.76*	12.7	17.6
12	3.47	18.7	4.89	12.5	16.1
13	5.34	18.7	7.75	11.9	16.4
14	9.56	18.7	10.72	11.6	17.6
15	11.67	18.7	12.66	11.0	19.0
16	11.52	19.0	12.37	11.3	21.5
17	8.33	19.3	9.06	10.8	26.3
18	7.47	18.4	8.09*	10.8	32.9
19	7.62	18.1	8.27	10.5	28.6
20	6.51	18.4	7.18	10.2	22.4
21	5.24	18.7	5.92	9.9	16.7
22	4.67	19.0	5.37	9.6	11.9
23	4.39	19.5	5.09	9.3	9.1
24	4.96	18.7	5.72	9.3	8.2
25	5.28	17.0	6.10	8.8	7.9
26	4.40	15.0	5.31	8.5	7.6
27	4.46	12.5	5.41*	8.5	7.4

Table E-1 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Jun 28	5.45	9.9	6.30	8.2	7.4
29	5.24	7.1	5.95	7.9	7.1
30	4.96	5.1	5.56*	7.9	7.1
Jul 1	4.81	5.9	5.31	7.9	5.7
2	4.46	7.6	4.81	7.4	4.5
3	3.98	6.5	4.23*	7.4	4.5
4	5.32	5.1	5.61	7.1	4.0
5	4.67	5.7	4.97	7.1	4.0
6	3.96	5.4	4.28	7.1	4.8
7	3.40	5.1	3.73*	7.1	5.4
8	2.93	5.4	3.28	7.4	4.8
9	3.03	5.7	3.40	7.4	4.5
10	2.71	5.4	3.10	7.1	4.0
11	1.97	4.8	2.37*	6.8	3.7
12	1.68	4.5	2.19	6.5	3.1
13	1.48	4.5	2.05	6.5	2.8
14	1.60	5.7	2.23*	7.1	2.3
15	1.47	5.7	2.08	7.1	2.3
16	1.55	6.2	2.10	7.1	2.3
17	1.08	5.9	1.61*	7.1	2.3
18	0.83	5.7	1.33	7.1	2.0
19	0.75	5.1	1.23	7.1	2.0
20	0.80	4.8	1.25	7.4	2.0
21	0.69	4.5	1.09*	7.4	2.0
22	0.56	4.2	0.95	7.4	2.0
23	0.51	4.0	0.89	7.4	2.0
24	0.47	4.0	0.82	7.1	2.0
25	0.46	3.7	0.80*	6.8	2.0
26	0.47	2.8	0.82	6.8	2.3
27	0.49	2.8	0.85	6.5	2.0
28	0.51	2.3	0.86	6.8	2.0
29	0.67	2.8	1.04	6.8	2.3
30	0.69	3.4	1.07*	7.1	2.0
31	0.61	3.1	0.94	7.1	2.0
Aug 1	0.59	2.8	0.85	7.1	1.7
2	0.47	2.5	0.72	6.8	1.7
3	0.47	2.3	0.73	7.1	1.4
4	0.44	2.3	0.71*	6.5	1.1
5	0.35	2.3	0.61	6.5	1.1
6	0.37	2.3	0.63	6.8	1.1
7	0.34	2.0	0.59*	6.5	1.1
8	0.29	2.0	0.53	6.5	1.1
9	0.30	2.0	0.52	6.5	1.1
10	0.43	1.7	0.66*	6.2	1.1
11	0.47	1.7	0.71	5.9	1.0
12	0.54	1.7	0.79	5.7	1.0
13	0.59	2.5	0.88	5.4	1.0
14	0.55	2.0	0.86*	5.4	1.0

Table E-1 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Aug 15	0.52	2.0	0.82	5.4	1.0
16	0.50	1.7	0.78	5.4	1.0
17	0.48	1.7	0.77*	5.4	1.0
18	0.53	1.7	0.80	5.4	1.0
19	0.53	1.7	0.78	5.4	1.0
20	0.52	1.7	0.76	5.4	1.0
21	0.55	4.0	0.77*	5.4	1.0
22	0.54	5.1	0.76	4.8	1.0
23	0.44	2.3	0.67	4.2	1.0
24	0.45	1.7	0.69*	4.0	1.0
25	0.43	1.7	0.67	3.4	1.0
26	0.42	1.7	0.66	2.8	1.1
27	0.43	1.4	0.68	2.5	1.1
28	0.39	1.4	0.64*	2.3	1.1
29	0.35	1.4	0.59	2.3	1.1
30	0.33	1.4	0.58	2.3	1.1
31	0.32	1.4	0.57	2.3	1.1
Sep 1	0.30	1.4	0.55	2.3	1.0
2	0.31	1.4	0.55	2.0	1.0
3	0.30	1.4	0.54	2.0	1.0
4	0.29	1.1	0.53	2.0	0.9
5	0.29	1.1	0.54*	2.0	0.9
6	0.30	1.1	0.54	2.0	0.9
7	0.30	1.1	0.54	2.0	0.9
8	0.31	1.1	0.55	2.0	0.9
9	0.31	1.1	0.55	2.0	0.9
10	0.31	1.4	0.56	2.0	0.9
11	0.32	1.7	0.56	2.0	0.7
12	0.32	1.1	0.56	2.0	0.7
13	0.32	1.4	0.57*	2.0	0.7
14	0.33	1.4	0.57	2.0	0.7
15	0.33	1.1	0.58	2.0	0.7
16	0.34	1.1	0.59	2.0	0.7
17	0.35	1.1	0.60	1.7	0.7
18	0.35	1.1	0.61	1.7	0.7
19	0.36	1.1	0.62	1.7	0.7
20	0.36	1.1	0.63	1.7	0.6
21	0.37	0.9	0.64*	1.7	0.6
22	0.37	1.0	0.65	1.7	0.6
23	0.37	1.0	0.64	1.7	0.6
24	0.36	1.0	0.63	1.7	0.6
25	0.36	1.0	0.64	2.0	0.6
26	0.37	1.0	0.64	2.0	0.6
27	0.37	1.0	0.65	2.3	0.6
28	0.36	1.0	0.63*	2.3	0.6
29	0.36	1.0	0.64	2.3	0.6
30	0.31	1.0	0.59	2.3	0.6
Oct 1	0.31	1.0	0.59	2.3	0.6

Table E-1 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Oct 2	0.31	1.0	0.59	2.3	0.6
3	0.31	1.0	0.59*	2.3	0.6
4	0.25	1.0	0.52	2.3	0.6
5	0.26	1.0	0.52	2.3	0.6
6	0.28	1.0	0.53	2.3	0.7
7	0.29	1.0	0.54	2.3	0.7
8	0.28	1.0	0.52	2.3	0.6
9	0.30	1.1	0.52	2.3	0.6
10	0.31	1.1	0.54*	2.3	0.6
11	0.31	1.1	0.54	2.3	0.7
12	0.31	1.1	0.55	2.3	0.7
13	0.31	1.1	0.57	2.3	0.6
14	0.32	1.1	0.58	2.3	0.6
15	0.32	1.1	0.59	2.3	0.8
16	0.30	1.1	0.58	2.3	0.6
17	0.29	1.1	0.58*	2.8	0.6
18	0.28	1.1	0.58	2.8	0.6
19	0.28	1.1	0.58	2.8	0.6
20	0.26	1.4	0.56	2.8	0.6
21	0.25	1.7	0.55	2.8	0.6
22	0.25	2.0	0.54	2.8	0.6
23	0.24	2.0	0.54	2.8	0.6
24	0.24	2.3	0.53*	2.8	0.6
25	0.46	2.0	0.74	2.8	0.6
26	0.46	2.0	0.75	2.8	0.6
27	0.45	1.8	0.74	3.1	0.6
28	0.44	1.7	0.73	3.1	0.6
29	0.44	1.7	0.73	3.1	0.6
30	0.44	1.7	0.74	3.1	0.6
31	0.44	1.7	0.74	3.7	0.6
Nov 1	0.43	1.7	0.71	3.7	0.6
2	0.42	1.7	0.71	3.7	0.6
3	0.42	1.7	0.70	3.1	0.6
4	0.42	1.7	0.70	3.1	0.6
5	0.42	1.7	0.69	3.1	0.6
6	0.42	1.7	0.69	2.8	0.6
7	0.42	1.7	0.69*	2.8	0.6
8	0.43	3.4	0.68	2.8	0.6
9	0.40	3.1	0.65	2.8	0.6
10	0.43	2.5	0.67	2.8	0.6
11	0.42	2.0	0.65	2.8	0.6
12	0.44	2.0	0.66	2.8	0.6
13	0.45	1.7	0.65	2.8	0.6
14	0.47	1.7	0.65	2.8	0.6
15	0.48	1.1	0.66*	2.8	0.6
16	0.63	1.1	0.81	2.8	0.6
17	0.52	1.1	0.71	2.8	0.3
18	0.77	1.1	0.99	2.8	0.3

Table E-1 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Nov 19	0.53	0.9	0.76	2.8	0.3
20	0.53	0.9	0.75	2.8	0.3
21	0.53	0.9	0.75	2.8	0.3
22	0.53	0.9	0.75	2.8	0.3
23	0.53	0.9	0.75	2.8	0.3
24	0.53	0.9	0.75	2.8	0.3
25	0.50	0.6	0.72	2.8	0.0
26	0.50	0.6	0.72	2.8	0.0
27	0.50	0.6	0.72	2.8	0.0
28	0.50	0.6	0.72	2.8	0.0
29	0.50	0.6	0.72	2.8	0.0
30	0.48	0.6	0.70	2.5	0.0

*Indicates actual measurement taken at Station C6.

Table E-2

Mean Daily Discharges, 1976

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
Mar 22	0.68	-	1.12	-	-
23	0.47	1.7	0.95	0.1	4.1
24	0.46	1.9	0.97	0.1	4.4
25	0.44	2.7	0.98*	0.1	5.7
26	0.39	2.7	1.18	0.1	6.1
27	0.55	2.8	1.54*	0.1	7.2
28	0.51	3.1	1.42	0.1	8.2
29	0.51	2.9	1.27	0.1	8.9
30	0.49	2.4	1.14*	0.1	8.5
31	0.49	2.7	1.20	0.2	8.6
Apr 1	0.49	6.3	1.23*	0.2	9.8
2	0.51	5.7	1.30	0.6	10.5
3	0.55	6.4	1.37*	0.8	11.0
4	0.52	7.2	1.31	1.1	11.6
5	0.54	9.5	1.32	1.4	12.2
6	0.54	10.7	1.28*	1.7	14.4
7	0.48	9.4	1.33	5.7	17.0
8	0.50	8.7	1.44	8.5	19.3
9	0.60	9.4	1.59*	10.9	21.0
10	0.65	9.6	1.61	19.8	20.7
11	0.64	10.4	1.67*	25.7	20.1
12	0.84	12.8	1.72	25.4	21.8
13	0.83	16.9	1.64*	30.7	23.6
14	0.76	18.4	1.52	28.3	22.4
15	0.75	13.5	1.45*	27.3	19.8
16	0.72	17.8	1.48	26.5	17.5
17	0.71	25.3	1.49*	25.3	16.6
18	0.68	30.6	1.56	21.8	15.1
19	0.65	43.0	1.59	17.8	13.7
20	0.63	39.9	1.64*	15.4	11.0
21	0.64	29.6	1.44	14.9	9.9
22	0.70	27.0	1.33*	14.9	9.3
23	0.71	24.5	1.36	15.6	8.6
24	0.61	21.2	1.28	15.0	9.7
25	0.59	19.1	1.62*	14.9	12.8
26	0.61	18.5	1.52	15.9	10.2
27	0.60	16.3	1.28*	16.3	8.6
28	0.66	17.0	1.31	15.9	8.2
29	0.76	17.6	1.39	16.7	7.9
30	0.79	17.8	1.38*	17.4	7.6
May 1	0.71	14.4	1.39	17.4	7.6
2	0.79	10.1	1.55*	16.7	7.4
3	0.86	9.0	1.63	16.3	7.1
4	0.92	8.0	1.69*	16.2	6.8
5	1.04	11.8	1.78	15.9	6.8
6	1.26	11.4	1.98*	16.7	6.6
7	1.22	9.5	1.93	17.4	6.8

Table E-2 (Cont'd)

Date	C2 m^3/sec	C3 $m^3/secx10^3$	C6* m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
May 8	1.56	12.7	2.24*	17.6	7.1
9	1.38	12.1	2.12	18.9	8.4
10	1.46	11.1	2.23	15.6	10.1
11	1.67	10.7	2.49*	16.1	9.7
12	1.56	9.7	2.38	15.3	9.0
13	1.43	9.9	2.21*	15.1	9.0
14	1.95	8.9	2.75	13.3	8.5
15	1.96	6.1	2.78	12.6	7.7
16	1.60	8.5	2.45*	12.0	7.0
17	1.91	10.8	2.59	11.3	6.6
18	2.17	10.1	2.74*	10.8	6.6
19	2.36	9.4	2.97	16.3	8.5
20	2.87	10.2	2.51	22.3	8.4
21	2.18	10.0	2.85*	21.0	9.2
22	2.07	10.7	2.72	21.6	8.9
23	2.31	10.7	2.93	22.1	9.2
24	3.45	10.3	4.06*	20.5	10.9
25	3.06	10.1	3.91	18.6	8.3
26	2.46	9.7	3.51*	11.7	8.1
27	2.87	8.9	3.77	11.1	7.8
28	3.60	7.8	4.34*	10.6	7.6
29	4.36	7.1	4.96	9.2	7.2
30	4.92	6.8	5.38	7.1	6.9
31	3.18	6.6	3.51*	7.1	6.3
Jun 1	3.56	6.3	3.97	7.1	6.1
2	5.04	6.1	5.42*	7.1	6.1
3	5.19	5.6	5.64	6.6	6.5
4	7.25	5.6	7.79*	6.6	6.6

*Indicates actual measurement taken at Station C6.

Table E-3

Discharge at the Time Monthly Water Quality Samples Were Taken

Month	C2 m^3/sec	C3 $m^3/secx10^3$	C6 m^3/sec	C9 $m^3/secx10^3$	C10 $m^3/secx10^3$
4/75	0.31	2.4	0.55	3.3	3.3
5/75	0.57	38.2	0.82	25.2	29.9
6/75	3.88	18.7	-	14.2	21.0
7/75	4.14	6.5	5.55	8.6	5.9
8/75	0.78	2.6	0.96	7.7	2.3
9/75	0.32	0.9	-	2.3	4.7
10/75	0.29	1.1	0.57	1.7	0.6
11/75	0.37	1.7	0.60	2.6	0.4
12/17/75	0.32	0.9	-	-	-
1/76	-	-	-	-	-
2/76	0.28	-	-	-	-
3/ 2/76	-	-	-	-	1.7
3/31/76	1.07	2.0	1.12	0.0	7.7
5/ 5/76	1.01	12.2	1.59	15.6	7.7
6/ 2/76	-	5.9	5.24	6.5	5.9

Appendix F

Saturated Paste Data - Soil and Spoil Analyses

Table F-1

1976 Samples

Sample No.	Cond. (μmhos/cm)	Sample No.	Cond. (μmhos/cm)
SS100		SS105	
0	2700	0	300
30	2900	30	600
60	3500	60	300
SS101		SS106	
0	500	0	500
45	700	30	3000
120	200	60	4000
SS102		SS107	
0	1200	0	200
30	2600	30	300
60	2600	120	500
SS103		SS108	
0	300	0	300
30	3100	30	200
-	-	60	400
-	-	120	1400
SS104		SS109	
0	500	0	1800
30	300	45	2700

Appendix G

Leaching Data - Composite Spoil Sample

Table G-1

Sample Size Distribution

Size	Weight (gm)
Greater than 8 MM	248.3
Greater than 5 Mesh	247.4
Greater than 9 Mesh	256.0
Greater than 16 Mesh	236.8
Greater than 32 Mesh	201.4
Greater than 35 Mesh	23.2
Greater than 60 Mesh	74.6
Greater than 80 Mesh	35.0
Greater than 100 Mesh	14.1
Greater than 120 Mesh	7.9
Greater than 200 Mesh	22.3
Less than 200 Mesh	19.4

Table G-2

Results of Leaching Test

Volume Leachate (mℓ)	pH	Spec. Cond. @25°C (μmho/cm)	K (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	Ca (mg/ℓ)	Zn (mg/ℓ)	Cl (mg/ℓ)	$CaCO_3$ Total Hard. (mg/ℓ)	$CaCO_3$ Alkalinity (mg/ℓ)
			First Run (Initial Conditions)							
100	7.75	1470								
200	7.70	1394								
300	7.64	1314								
400	7.61	1247	22.0	20.8	80.3	231	0.058	0.12	995	94.7
500	7.63	1220								
600	7.68	1200								
700	7.50	1000								
800	7.92	941								
900	7.90	867								
1000	7.82	787								
1100	7.82	728	27.0	9.9	49.2	158	0.21	12.5	660	89.3
1200	7.87	677								
1300	7.92	630								
1400	7.95	570								
1500	8.05	500								
1600	8.02	480								
1700	8.02	450	18.0	5.4	31.0	99	0.020	3.0	425	88.6
1800	8.09	437								
1900	8.11	413								
2000	8.11	413						0.96	321	76.6
2100	8.01	406								
2200	7.99	372								
2300	8.10	336	9.0	4.1	19.8	81	0.018	0.48	231	72.6
2400	8.10	318								
2500	8.11	300								
2600	7.98	300								
2700	8.08	281								
2800	8.10	270								
2900	8.10	270								
3000	8.09	262	6.7	3.0	14.7	61	0.017	0.27	168	69.1
3100	8.10	250								
3200	8.15	248								
3300	8.10	248								
3400	8.12	240								
3500	8.10	313								
3600	8.11	296	5.1	2.6	13.0	50	0.012	0.29	166	67.5
3700	8.10	277								
3800	8.11	272								
3900	8.10	257								
4000	8.12	255								
4100	8.13	257	4.8	2.6	11.0	48	0.012	0.27	165	64.4
4200	8.14	255								
4260	8.15	306								

Table G-2 (Cont'd)

Volume Leachate (mℓ)	pH	Spec. Cond. @25°C (μmho/cm)	K (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	Ca (mg/ℓ)	Zn (mg/ℓ)	Cl (mg/ℓ)	$CaCO_3$ Total Hard. (mg/ℓ)	$CaCO_3$ Alkalinity (mg/ℓ)
			Second Run (After 60 hr aeration)							
4360	7.80	450								
4460	7.88	290								
4560	7.90	257	3.4	1.06	7.2	20.4	0.0105			
4660	7.93	206								
4760	7.95	200								
4860	8.02	182						0.39	147	33.9
4960	8.11	168								
5060	8.06	146	2.1	0.620	4.1	12.0	0.009			
5160	8.98	140								
5260	8.02	134						0.34	85.6	32.2
5360	8.12	124								
5460	8.11	122								
5560	8.18	118	1.7	0.459	3.0	8.0	0.007			
5660	8.22	107								
5760	8.31	92.4						0.48	61.8	30.1
5860	8.27	85.3								
5960	8.24	85.3								
6060	8.31	83.1	2.0	0.380	2.3	6.5	0.005			
6160	8.43	83.0								
6260	8.47	83.1						0.27	47.9	29.3
6360	8.42	82.5								
6460	8.33	77.8								
6560	8.40	72.0	1.5	0.330	1.9	6.2	0.004			
6660	8.34	67.5								
6760	8.52	67.0						0.26	41.3	26.0
6860	8.55	63.0								
6960	8.44	61.9								
7060	8.51	61.9	1.6	0.288	1.6	5.4	0.0025			
7160	8.49	61.5								
7260	8.50	59.5						0.23	36.1	25.3
7360	8.45	59.5								
7460	8.42	59.5								
7560	8.58	60.0	1.2	0.280	1.5	5.8	-			
7660	8.55	62.5								
7760	8.60	64.1								
7860	8.49	62.0						0.26	36.9	26.9

Table G-2 (Cont'd)

Volume Leachate (mℓ)	pH	Spec. Cond. @25°C (μmho/cm)	K (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	Ca (mg/ℓ)	Zn (mg/ℓ)	Cl (mg/ℓ)	$CaCO_3$ Total Hard. (mg/ℓ)	$CaCO_3$ Alkalinity (mg/ℓ)
			Third Run (After 120 hr aeration)							
7985	7.80	1293								
8010	7.90	990	6.9	10.3	62.9	211.0	0.049	0.72	-	-
8035	8.03	943								
8060	8.30	901								
8085	8.37	903								
8110	8.31	889								
8135	8.36	862	11.2	8.2	39.2	130	0.60	0.21	-	-
8160	8.38	858								
8185	8.40	830								
8210	8.44	847								
8235	8.19	820	12.8	9.6	38.0	124	0.022	24.2	-	-
8260	8.24	820								
8285	8.40	801								
8310	8.41	797	11.0	6.7	34.6	112	0.016	9.1	-	-
8360	8.42	796	12.0	7.1	35.0	106	0.011			
8860	8.00	676	8.4	4.9	27.0	80	0.018		-	-
9260	8.10	526	4.0	2.4	12.7	43	0.025			
			Fourth Run (After drying & crushing)							
9360	7.18	518								
9460	7.39	441								
9560	7.80	346	6.4	4.4	22.8	64.0	0.021	-		
9660	7.93	271								
9760	8.21	248								
9860	8.28	233							227	135
9960	8.33	198								
10060	8.30	175	4.1	0.860	9.7	28.9	0.016	-		
10160	8.30	164								
10260	8.18	161								
10360	8.20	147							103	131
10460	8.19	139								
10560	8.22	132	3.5	0.83	6.5	20.6	0.011	-		
10660	8.25	127								
10760	8.05	115								
10860	8.01	110							71	109
10960	8.01	107								
11060	8.10	102	2.8	0.42	4.7	15.7	0.011	-		
11160	8.15	93								
11260	8.24	89								
11360	8.10	90							56	86
11460	8.14	89								
11560	8.19	87	2.3	0.30	3.9	13.7	0.010	-		
11660	8.13	85								
11760	8.25	81								
11860	8.12	87							48	76
11960	8.14	87	2.1	0.31	3.8	14.0	0.020			
12010	8.52	88.5							47.8	76